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B. T. GALLOWAY, *Chief of Bureau.*

EXPERIMENTS IN WHEAT BREEDING:

EXPERIMENTAL ERROR IN THE NURSERY AND VARIATION IN NITROGEN AND YIELD.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., *October 16, 1912.*

Sir: I have the honor to transmit herewith and to recommend for publication as Bulletin No. 269 of the series of this Bureau the accompanying paper entitled "Experiments in Wheat Breeding: Experimental Error in the Nursery and Variation in Nitrogen and Yield," by Prof. E. G. Montgomery. This paper contains the results of special experiments in wheat breeding conducted by the Nebraska Agricultural Experiment Station in cooperation with the Office of Cereal Investigations of this Bureau, during the years 1905 to 1910, inclusive. In part, the work is a continuation of that recorded in Bureau of Plant Industry Bulletin No. 78, by Dr. T. L. Lyon, under whose direction the experiments were conducted from 1902 to 1906, inclusive. From 1907 to 1910, inclusive, the work was under the charge of Prof. Montgomery, experimental agronomist of the Nebraska experiment station, who has since become professor of farm crops in the College of Agriculture at Cornell University.

The paper is concerned chiefly with the nature and extent of experimental error in the wheat nursery in connection with breeding experiments in the inheritance of nitrogen content and yield in wheat plants. The standardization of agronomic experiments has been receiving much attention in recent years and is regarded as of fundamental importance in agronomic research. The results contained in this paper are presented as a contribution to this subject as well as to the improvement of wheat.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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EXPERIMENTS IN WHEAT BREEDING: EXPERIMENTAL ERROR IN THE NURSERY AND VARIATION IN NITROGEN AND YIELD.

I.—EXPERIMENTAL ERROR IN THE NURSERY AND VARIATION IN NITROGEN CONTENT.

INTRODUCTION.

The investigation of the variation of plants of winter wheat in relative nitrogen content when grown under field or nursery conditions was begun by Dr. T. L. Lyon, formerly agronomist of the Nebraska Agricultural Experiment Station, in collaboration with the Bureau of Plant Industry of the United States Department of Agriculture. His results were published as a bulletin of that bureau.[1] Since 1907 the investigation has been continued by the writer and his assistants.[2]

One of the striking features of the data obtained by Dr. Lyon was the variation in nitrogen content of the kernels from different plants of wheat grown under apparently similar conditions. For example, 800 spikes of Turkey wheat were selected and half of each spike analyzed for proteid nitrogen, the lowest having only 1.12 per cent while the highest contained 4.95 per cent.

In 1903, 288 plants which were the progeny from 119 of the spikes analyzing above 3 per cent proteid nitrogen in 1902 were analyzed and found to vary from 1.20 per cent to 5.85 per cent in nitrogen content. In most of the families only a single plant was selected for analysis, but in the remainder two to six plants were selected. Even where all the plants were grown from a single parent the variation was quite as great.

[1] Lyon, T. L. Improving the Quality of Wheat. Bulletin 78, Bureau of Plant Industry. 1905.

[2] The writer wishes to acknowledge with thanks the assistance of a number of men who have contributed to the production of these data. Dr. T. L. Lyon, now of Cornell University, planted the first wheat nursery in 1902 and conducted the work until 1906, being assisted by Prof. Alvin Keyser, now of the Colorado Agricultural Experiment Station. They left an excellent set of records, from which data previous to 1906 have been prepared (Table II). Mr. L. L. Zook, now of the Bureau of Plant Industry, assisted with the work in 1907 and 1908, as did Mr. Erwin Hopt in 1908 and 1909. Prof. T. A. Kiesselbach had charge of the records during the seasons of 1909 and 1910 and has prepared much of the tabular matter for publication. The chemical analysis has been under the direction of Dr. F. J. Alway, who devised a rapid method especially for this work.

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Dr. Lyon noted this variation, as follows:

For instance, the plants numbered 21205 to 21212, all of which come from the same parent, vary from 2.16 to 5.23 per cent in proteid nitrogen content, while plants 69805 and 69806 vary from 5.82 to 1.66 per cent in this constituent.[1]

In addition to the 119 "highs" preserved in 1903, progeny were analyzed also from 20 "mediums" and "lows." When these data were summarized it seemed that there had been some tendency to transmit the character, as shown in Table I.

TABLE I.—*Results of a study of transmission of nitrogen content in wheat kernels in 1902 and 1903.*[2]

Range in percentage of proteid nitrogen.	1902		1903	
	Number of analyses averaged.	Proteid nitrogen in kernels.	Number of analyses averaged.	Proteid nitrogen in kernels.
		Per cent.		*Per cent.*
1 to 3	20	1.85	70	2.59
3 and over	119	3.39	288	2.92

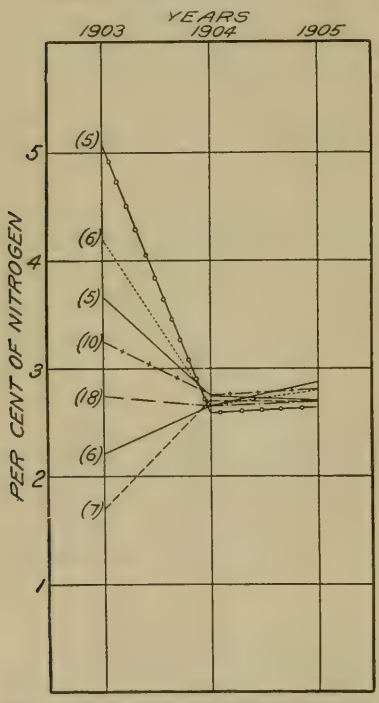

FIG. 1.—Diagram showing the transmission of nitrogen content in 57 wheat plants of 1903 to progeny in 1904 and 1905. The vertical lines represent successive years. The horizontal lines represent the percentage of nitrogen found, and the figures in parentheses show the number of plants in each group analyzed for nitrogen content in 1903.

Summaries of the results obtained in 1904 and 1905 show very little tendency to transmit this character.

In 1906, after four years of selection of extremely high fluctuates, and later, after two more years of selection, by taking a composite sample of all the progeny of a plant it was found that no gain had been made in the nitrogen content of the crop.

In Table II is a summary of data obtained in the years 1903 to 1905 from 57 of the original plants. Figure 1 is a graphic presentation of the same data, in which the horizontal lines represent the percentage of nitrogen, the vertical lines represent successive years, and the figures in parentheses show the numbers of plants in each of the seven groups analyzed for nitrogen content in 1903.

[1] Lyon, T. L. Op. cit., p. 99.

[2] Lyon, T. L. Op. cit., table 26, p. 98.

TABLE II.—*Nitrogen content of 57 wheat plants in 1903 and of their progeny in 1904 and 1905, arranged in groups according to the percentage of nitrogen.*

Record of 57 plants harvested in 1903.					Record of progeny plants in 1904.					Record of progeny plants in 1905.				
	Kernels per plant.		Nitrogen in kernels.			Kernels per plant.		Nitrogen in kernels.			Kernels per plant.		Nitrogen in kernels.	
Number of analyses.	Average number.	Weight.	Per cent.	Weight.	Number of analyses.	Average number.	Weight.	Per cent.	Weight.	Number of analyses.	Average number.	Weight.	Per cent.	Weight.
		Gms.		*Gms.*			*Gms.*		*Gms.*			*Gms.*		*Gms.*
7	555	10.82	1.68	0.1709	35	641	9.12	2.69	0.2491	112	1,052	17.71	2.68	0.4606
6	654	14.66	2.20	.3040	35	790	12.63	2.63	.3262	99	1,040	19.13	2.84	.5207
18	601	11.26	2.74	.3068	90	745	11.42	2.64	.2985	285	1,165	21.44	2.69	.5716
10	338	5.87	3.27	.1919	53	694	10.59	2.74	.2947	180	1,057	19.49	2.82	.5486
5	306	6.44	3.68	.2431	23	723	10.56	2.74	.2875	51	1,093	23.16	2.71	.6154
6	366	6.62	4.25	.2837	30	779	11.54	2.65	.3137	98	1,245	22.02	2.80	.6153
5	274	5.68	5.13	.2773	25	716	10.56	2.59	.2710	81	1,183	20.12	2.64	.5317

It is difficult to explain why such great variations exist when there seems to be little or no tendency to transmit them. It seems apparent that the variations must be due to differences in environment. Since the ordinary factors of environment, as sunlight, warmth, moisture, and apparent fertility of the soil, are constant for all plants under our nursery conditions, we must conclude that there are factors profoundly influencing the growth of plants beyond the ordinary range of observation.

Figure 2 shows the general appearance of the centgener nursery, each centgener containing 100 plants 6 inches apart each way. Figure 3 shows a single centgener just after growth has started in the spring, about 40 per cent of the plants having winterkilled. The great variation in the size of the remaining plants is probably due to the effect of environment and is not hereditary. This environmental variation is usually noted even in centgeners where most plants have survived and is often interpreted as indicating real hereditary differences.

A number of interesting problems are suggested. Why should one plant, growing under practically the same environment as another, collect from the soil two or three times as much nitrogen? Or why should two plants yielding different quantities of grain collect the same quantities of nitrogen? Table III illustrates these variations.

TABLE III.—*Data from six wheat plants, showing irregular variation in yield and in nitrogen content of grain.*

Plant No.	Kernels.		Nitrogen in kernels.		Plant No.	Kernels.		Nitrogen in kernels.	
	Number.	Weight.	Per cent.	Total weight.		Number.	Weight.	Per cent.	Total weight.
		Grams.		*Grams.*			*Grams.*		*Grams.*
21107.....	1,058	22.879	2.45	0.5605	23905.....	776	18.507	3.57	0.6607
21108.....	1,030	16.679	2.59	.4324	23907.....	1,167	23.018	2.86	.6583
21109.....	927	16.026	1.74	.2789	24005.....	1,495	30.064	2.19	.6584

The three plants, Nos. 21107 to 21109, are from the same mother growing in a single centgener, probably less than 2 feet apart, yet the actual grams of nitrogen gathered differ more than 100 per

FIG. 2.—Centgener nursery, Nebraska Agricultural Experiment Station. Each centgener contains 100 plants.

cent. This difference is not inherited, as these plants rarely transmit this quality. It therefore seems hard to explain on a difference in the root development or in the functioning parts of the plant. As plants growing only 6 inches apart commonly exhibit such differences, it can not be ascribed to a difference in soil solution. Difference in vigor of growth is not a satisfactory explanation, as plants Nos. 23905, 23907, and 24005 illustrate. These three plants under uniform conditions yielded different quantities of grain, yet the heaviest yielder produced no more nitrogen than the lowest. Such differences are not only common among plants from the same centgener, but quite marked variations are also noted between centgeners from the same mother plant.

Some of the results obtained from the study of this problem are shown in figures 4 and 5. Figure 4 is a plat of a single centgener (1907), with the plants 6 inches apart each way, making the entire area 5 feet square. All plants in this centgener are from the same parent. Each square represents a plant. Where no figures occur the plant was missing. The upper number shows the percentage of nitrogen, the central number represents the kernels borne by the plant, and the lower number the weight in grams of the good kernels. Each plant was harvested separately, the kernels counted and weighed, and the percentage of nitrogen determined. Two wave lines indicate plants analyzing above 3 per cent nitrogen and one wave line those

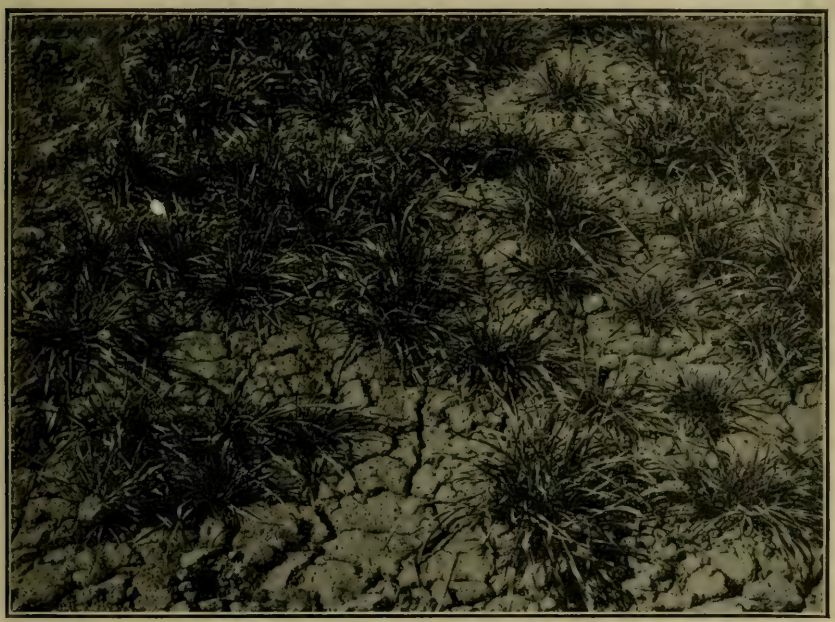

FIG. 3.—Wheat centgener just after growth has started in spring, showing about 40 per cent of the plants winterkilled. Note the great variation in size of the remaining plants.

analyzing between 2.8 and 3 per cent. A tendency to group is noted. Those containing between 2.56 and 2.80 per cent are not marked. One straight line indicates plants with between 2.55 and 2.40 per cent of nitrogen; two straight lines, less than 2.40 per cent.

Figure 5 shows a section of the wheat nursery in 1907. The small squares represent centgeners 5 feet square and the heavy lines outline family groups; that is, all the plants and centgeners within a heavy line came from the same original plant. The percentage of nitrogen was obtained by taking a composite sample from all plants on the centgener. Variation is quite marked, although there is some tendency for certain families to run high or low; as, for example, family 339.

An illustration of the irregularities in number and weight of kernels, in percentage of nitrogen, and in total yield of nitrogen per plant is afforded in Table IV, pedigree records of two families. The wide variations were supposed at first to represent natural fluctuations which would be in some degree transmitted, but the selection of these high fluctuations has had no apparent effect in modifying the

2.99 682 17.8	2.32 429 13.0	2.46 450 14.0	2.24 385 12.8	2.21 247 6.80	2.32 299 8.86	2.52 501 13.4	2.52 361 10.0		2.55 445 15.7
3.04 225 5.8	2.79 500 15.5	2.52 481 13.4	2.41 284 8.1	2.60 507 13.8	2.60 401 11.1	2.68 347 9.8	2.63 549 15.0	2.52 411 11.8	2.72 513 12.5
2.86 535 14.3	2.60 633 16.7	2.56 657 18.6	2.56 562 14.5	2.53 409 9.8	2.50 417 10.1	2.56 227 5.3	2.75 543 14.3	2.82 298 7.0	2.56 681 17.5
3.06 325 4.9	2.73 767 18.7		2.50 225 5.0	2.29 410 11.0	2.56 284 8.0	2.63 390 9.4	2.66 378 9.3	2.83 466 10.4	3.09 423 8.9
2.62 957 25.2	2.59 715 18.2		2.49 464 10.8	2.45 322 8.9	2.75 406 9.7	2.69 392 9.5	3.16 218 3.8	3.10 352 7.6	3.58 144 2.8
		2.89 535 11.1	2.65 141 3.1	2.42 363 8.5	2.90 251 5.2	2.96 228 4.8	3.09 319 6.6	3.20 490 6.0	3.38 421 9.5
2.75 719 22.2	2.46 382 10.3	2.55 421 11.9	2.41 155 4.1	2.71 457 5.3		2.86 425 8.9	2.60 379 7.4	3.10 295 6.3	
2.59 290 7.1	2.60 600 18.8	2.28 425 10.4	2.28 329 9.0	2.66 470 11.1	2.76 239 5.5	2.77 362 4.8	3.07 194 3.3	3.27 510 10.8	2.90 368 6.5
	2.15 292 7.4	2.39 325 8.7	2.63 460 17.4	2.52 661 16.8		2.80 641 14.4	2.96 466 11.1	2.89 488 11.8	
	2.66 832 22.9	2.18 258 7.6	2.48 716 19.6	2.58 576 14.4	2.60 510 12.1	2.80 540 14.6	2.82 339 7.0	2.58 313 8.1	3.11 395 7.5

FIG. 4.—Wheat centgener of 100 plants, showing variations in yield of grain and of nitrogen in 1907. Upper figures, percentage of nitrogen content; middle figures, number of kernels produced; lower figures, weight of good kernels in grams. The various underscorings of the upper figures indicate five groups having successively higher nitrogen content as follows: (1) Figures underscored with two straight lines lie between 2.15 and 2.40 per cent; (2) those underscored with one straight line lie between 2.41 and 2.55 per cent; (3) those not underscored lie between 2.56 and 2.59 per cent; (4) those underscored with one wave line lie between 2.80 and 3 per cent; (5) those underscored with two wave lines lie above 3 per cent.

nitrogen content of plants in a family, as there always seemed to be a mean content for each family, to which the types returned.

As examples of variation, note that No. 35809 in family 42 has a low yield of nitrogen, yet the yield of nitrogen found in its progeny is practically equal to that of other members of the family. In family 48 (Table IV) note that in 1903 the three plants selected analyzed 3.82, 4.43, and 5.48 per cent of nitrogen, respectively,

while the family as a whole contained 3.53 per cent. The progeny of these plants returned to normal in percentage and total yield of nitrogen, except No. 21909, in which the yield of grain was above the average. Just why these wide fluctuations occur when every precaution is taken to grow the plants under uniform conditions is not very apparent.

In 1908 a more thorough investigation of this point was made. Twenty-nine plants from the 1907 crop were all selected from a single centgener, and therefore all came from a single plant in 1906. From each of these 29 plants a centgener was planted, and also a row 14 feet long. The 29 centgeners were planted side by side, also the 29 rows. At harvest time all the plants in each of the 10 adjacent

2.35	2.66	2.65	2.93	3.04	2.89	2.73	2.56	2.59	2.89	2.77	2.62	2.55	2.77	2.71	2.55	2.89	2.48	2.77
313	314	314	328	328	381	381	385	385	405	405	417	417	522	522	556	556	3	3
2.46	2.60	2.72	3.00	2.45	2.72	2.75	2.71	2.72	2.50	2.83	2.63	2.58	2.93	2.99	2.52	2.52	2.68	3.02
313	314	314	328	328	381	381	385	385	391	405	417	417	522	522	556	556	3	3
2.56	2.62	2.69	2.93	2.92	2.57	2.82	2.53	2.62	2.53	3.00	2.53	2.49	2.93	3.11	2.59	2.68	2.50	2.36
313	314	314	317	338	381	385	385	385	391	405	417	417	522	522	556	556	3	3
2.58	2.60	2.63	2.73	3.17	2.83	2.53	2.53	2.76	2.49	2.89	2.59	2.63	2.66	2.95	2.55	2.66	2.55	3.03
313	314	316	317	339	381	385	385	385	391	405	417	417	522	522	556	556	632	3
2.34	2.69	2.84	2.60	3.16	2.80	3.02	2.66	2.93	3.06	2.87	2.75	2.71	2.89	2.92	2.39	2.63	2.62	2.96
313	314	316	317	339	381	385	385	390	391	407	417	417	522	555	556	556	632	3
2.72	2.76	2.87	2.87	3.17	2.89	2.49	2.80	2.71	2.48	2.89	2.60	2.68	2.89	2.68	2.92	2.69	2.68	2.98
313	314	316	317	339	381	385	385	390	391	407	417	417	522	555	556	556	632	3
2.46	2.95	2.93	2.90	3.09	2.79	2.60	2.89	2.75	2.77	2.82	3.00	2.77	3.00	2.83	2.83	2.83	2.56	2.83
313	314	316	317	339	381	385	385	390	391	407	408	417	522	555	556	556	632	3
2.62	2.80	2.89	2.73	313	2.45	2.63	2.56	2.76	2.68	2.92	2.84	2.71	3.03	2.97	2.59	2.79	2.62	2.89
313	314	316	317	332	379	385	385	390	391	408	408	425	522	555	555	556	556	3
2.85	2.59	2.76	2.63	2.58	2.87	2.73	2.68	2.60	2.68	2.69	2.89	2.66	2.72	3.02	2.73	2.76	2.69	2.68
313	314	316	317	377	379	385	385	390	391	408	408	425	425	555	555	556	556	3
2.87	2.44	2.86	2.63	2.46	2.82	2.73	2.63	2.86	2.66	2.59	2.83	2.52	2.63	2.77	2.73	2.68	2.71	2.66
314	314	316	317	377	379	385	385	390	391	408	408	425	425	555	555	556	556	3
2.87	2.80	3.00	2.71	2.79	2.34	2.66	2.49	2.65	2.68	2.79	2.87	2.90	2.62	3.16	2.84	2.72	1.76	2.68
314	314	316	317	377	379	385	385	390	391	408	408	425	425	555	555	556	556	3
2.77	2.58	2.96	2.72	2.63	3.20	2.73	2.73	2.72	2.77	2.84	3.02	2.66	2.65	2.79	2.90	2.62	2.11	2.73
314	314	316	317	377	377	385	385	390	390	408	408	425	425	555	556	556	556	3

FIG. 5.—Diagram of a portion of the wheat nursery in 1907, showing variations in nitrogen content in centgeners and families. Each square represents a single centgener, and each area within heavy lines shows the centgeners belonging to a single family. The upper figures represent the percentage of nitrogen; the lower figures are the family numbers.

centgeners were harvested in order and analyzed. The 10 duplicate rows were grown in a manner similar to field conditions; that is, sown at the rate of 5 pecks to the acre and the rows 8 inches apart. The plan was to see whether the same sort of variation would be found among plants under field conditions. To secure a uniform sample from the rows, 7 plants were harvested from each foot of row, 98 plants being harvested and analyzed from each row. In the centgeners the results were similar to those obtained in 1907. The plants in the rows, being planted close together, yielded only about one-tenth as much grain per plant, but the variation in yield and in percentage of nitrogen per plant was even greater than in the centgeners.

TABLE IV.—*Nitrogen content and yield of grain from families Nos. 42 and 48, from 1902 to 1905, inclusive.*

Original plant in 1902.		Record of progeny plants in 1903.					Record of progeny plants in 1904.					Record of progeny plants in 1905.				
Plant No.	Nitrogen in kernels.	Plant No.	Kernels per plant.		Nitrogen in kernels.		Plant No.	Kernels per plant.		Nitrogen in kernels.		Plant No.	Kernels per plant.		Nitrogen in kernels.	
			Number.	Weight.	Per cent.	Weight.		Number.	Weight.	Per cent.	Weight.		Number.	Weight.	Per cent.	Weight.
	Per cent.			*Grams.*		*Grams.*			*Grams.*		*Grams.*			*Grams.*		*Grams.*
												8005	843	13.600	2.60	0.3536
												8006	602	10.496	2.69	.2823
												8007	1,200	19.279	2.81	.5415
							35805	693	11.4281	2.63	.3006	8008	1,640	34.290	2.91	.9978
												8009	1,355	23.360	2.75	.6424
												Average.	1,128.0	20.205	2.75	.5635
												8105	924	17.356	2.72	.4721
		21305	312	6.2514	2.67	0.1669						8106	1,421	14.093	2.74	.3861
		21306	226	4.1516	2.90	.1204						8107	1,152	19.864	2.94	.5840
21301 (family 42).....	3.05	21307	142	2.5691	3.04	.0781	35806	406	10.2617	2.48	.2545	8108	1,727	37.730	2.84	1.0715
		21308	354	5.3080	3.45	.2004						8109	1,501	30.185	2.81	.8482
		Average.	258.7	4.6950	3.02	.1414						Average.	1,345.0	23.8456	2.81	.6724
												8405	950	21.365	2.83	.6005
							35807	538	8.4050	2.79	.2345	8406	715	15.219	2.87	.4368
							35808	739	8.4660	3.25	.2751	8407	1,091	22.852	2.65	.6056
							35809	571	10.945	1.26	.1272	8408	1,218	26.530	2.62	.6951
												8409	1,215	29.783	2.67	.7952
							Average.	589.4	9.7311	2.48	.2377	Average.	1,037.8	23.1498	2.73	.6266

| | | |

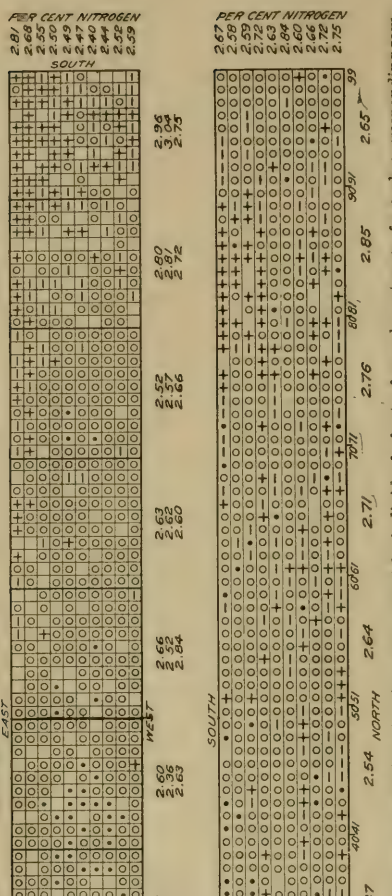

FIG. 6.—Diagram of 10 centgeners and 10 corresponding rows, showing variations in nitrogen content for individual plants, for each centgener, for each corresponding row, and also for their parents. The symbols used are as follows: Blank spaces indicate plants missing; dots, plants analyzing below 2.2 per cent nitrogen; circles, plants analyzing between 2.2 and 2.8 per cent; dashes, plants analyzing between 2.8 and 3 per cent; crosses, plants analyzing, 3 per cent and over.

Figure 6 is a graphic illustration of the centgener and row plats. The soil on which these plats were located was thought to be very uniform, and the appearance of the crop on the various plats was also uniform. The average per cent of nitrogen in the 10 centgeners varied from 2.27 (No. 41301) to 3.04 (No. 42001). To show the location of high and low nitrogen plants in each centgener the method of plotting shown in the figure was used. Where plants were missing the space is left blank; where a plant analyzed less than 2.20 per cent in nitrogen a dot (.) is used; from 2.20 to 2.80 per cent the circle is employed, denoting intermediates; from 2.80 to 3 per cent a dash (—) is used; and all plants analyzing above 3 per cent are marked by a cross (+). The "highs" and "lows" tend to segregate, as in 1907. Also there is a progressive increase toward one end of the series. The 10 duplicate rows are plotted in a similar manner. The rows were more uniform in composition than the centgeners, but they show a variation in composition from 2.58 to 2.84 per cent of nitrogen. Also there seems to be no consistent relation between the rows and the corresponding centgeners, or the parent

plants. The variation in both centgeners and rows seems to be due to local effects, and does not appear to be hereditary. We may eliminate any possibility of hereditary effect by adding together the short rows in the centgeners which come end to end, thus making 10 long rows with each centgener equally represented. The results of such composite analyses are shown at the right of the centgener plat, indicating a variation ranging from 2.40 to 2.81 in percentage of nitrogen in the 10 rows. In the same way we may divide the 10 original rows into blocks having each row equally represented. Variation in the 10 blocks thus formed is shown, at the bottom of figure 6, to be from 2.47 to 2.85 per cent of nitrogen.

RELATION OF YIELD OF GRAIN TO NITROGEN CONTENT.

Since some centgeners yield more grain than others, the 29 centgeners from the same parent plant, of which the 10 centgeners just considered were a part, were arranged according to percentage of nitrogen and summarized in groups of 5 centgeners. This summary (Table V) shows some relation between yield of grain per centgener and nitrogen content, the yield varying inversely with the nitrogen content, but when the 29 corresponding rows were arranged in the same way no such relation was shown.

TABLE V.—*Nitrogen content of 29 centgeners and corresponding rows from family No. 831 in 1908.*

Arranged according to nitrogen in centgeners.							Arranged according to nitrogen in rows.						
Number of centgeners.	Centgener.			Corresponding row.		Nitrogen in parent plants.	Number of rows.	Row.		Corresponding centgener.			Nitrogen in parent plants.
	Nitrogen.	Total yield.	Average yield per plant.	Nitrogen.	Total yield.			Nitrogen.	Total yield.	Nitrogen.	Total yield.	Average yield per plant.	
	P. ct.	*Grams.*	*Grams.*	*P. ct.*	*Grams.*	*Per cent.*		*P. ct.*	*Grms.*	*P. ct.*	*Grms.*	*Grms.*	*P. ct.*
5.....	2.83	616	7.19	2.67	194	2.69	5.....	2.78	189	2.63	652	7.52	2.65
5.....	2.63	614	7.13	2.66	200	2.68	5.....	2.72	196	2.57	763	9.03	2.73
5.....	2.56	851	9.60	2.65	173	2.63	5.....	2.65	194	2.52	817	9.14	2.72
5.....	2.52	767	9.01	2.57	179	2.66	5.....	2.60	195	2.57	789	11.13	2.62
5.....	2.44	799	9.01	2.52	189	2.71	5.....	2.55	188	2.55	777	8.72	2.64
4.....	2.34	916	10.50	2.64	209	2.68	4.....	2.35	176	2.50	729	8.50	2.68

TABLE VI.—*Nitrogen content and yield of grain from 180 wheat plants, arranged in inverse order of percentage of nitrogen, in groups of 10.*

NINETY PLANTS FROM CENTGENER NO. 41801.

Plant No.	Nitrogen.	Yield.	Plant No.	Nitrogen.	Yield.	Plant No.	Nitrogen.	Yield.
	Per ct.	*Grams.*		*Per ct.*	*Grams.*		*Per ct.*	*Grams.*
52	3.44	1.55	64	2.62	11.11	27	2.43	7.49
79	3.22	.60	83	2.62	16.23	47	2.43	7.11
61	3.21	7.86	93	2.62	19.49	59	2.43	6.60
81	3.19	4.36	9	2.61	9.16	78	2.43	7.39
91	3.19	6.45	51	2.61	1.20	26	2.41	7.48
41	3.17	7.92	31	2.60	7.00	63	2.41	14.83
22	3.13	4.89	67	2.60	3.11	20	2.40	10.37
12	3.00	13.42	8	2.58	8.22	35	2.39	8.82
6	2.98	10.65	16	2.58	6.45	48	2.39	1.44
61	2.98	7.54	54	2.58	6.76	69	2.39	8.40
Average	3.15	6.52	Average	2.60	8.87	Average	2.41	7.99
71	2.92	2.46	56	2.58	6.61	68	2.37	8.00
90	2.92	10.52	60	2.57	10.56	96	2.37	6.07
80	2.89	9.14	73	2.57	15.31	55	2.36	8.30
33	2.85	7.69	76	2.56	1.34	24	2.34	11.07
72	2.82	11.75	32	2.53	8.42	45	2.30	9.59
87	2.82	.45	95	2.51	12.25	25	2.29	13.16
23	2.79	11.46	14	2.50	17.52	58	2.29	8.19
42	2.78	6.82	18	2.48	11.22	28	2.27	7.90
75	2.77	7.59	49	2.48	6.15	36	2.27	8.60
97	2.77	4.44	50	2.48	4.69	44	2.27	6.85
Average	2.83	7.43	Average	2.52	9.41	Average	2.31	8.77
11	2.71	11.47	86	2.48	10.01	39	2.26	8.66
74	2.70	6.83	34	2.47	21.10	29	2.25	9.85
21	2.68	10.52	43	2.47	11.18	30	2.23	9.17
85	2.68	6.32	70	2.47	13.25	46	2.22	7.24
15	2.65	5.55	98	2.47	6.83	37	2.20	10.01
53	2.65	14.26	40	2.46	12.08	57	2.20	14.78
84	2.65	7.45	77	2.46	8.27	89	2.20	13.50
88	2.65	5.21	99	2.46	12.81	17	2.11	10.31
94	2.65	16.94	10	2.44	2.93	19	2.11	10.40
7	2.62	9.17	5	2.43	16.20	38	2.09	6.90
Average	2.66	9.47	Average	2.46	11.47	Average	2.19	10.08

NINETY PLANTS FROM ROW NO. 141801.

79	3.31	0.84	88	2.77	0.56	25	2.54	0.87
7	3.29	.26	8	2.76	1.69	31	2.54	1.54
57	3.25	.30	18	2.76	1.08	40	2.54	1.07
11	3.20	.35	99	2.76	3.41	72	2.53	1.72
9	3.19	.77	49	2.75	1.29	73	2.53	2.42
76	3.18	.44	46	2.74	2.51	77	2.52	.10
80	3.18	.79	89	2.74	1.30	62	2.51	.66
5	3.17	1.94	15	2.71	.53	33	2.48	1.62
87	3.10	.33	38	2.69	.63	35	2.48	4.32
14	3.09	.96	10	2.67	.18	69	2.47	2.00
Average	3.20	.70	Average	2.73	1.32	Average	2.51	1.63
83	3.09	.30	50	2.67	.65	81	2.47	1.46
16	3.08	.65	32	2.66	1.01	95	2.47	2.07
17	3.07	.79	64	2.66	1.21	37	2.45	.60
20	3.05	.69	93	2.66	1.29	39	2.45	.81
23	3.02	2.37	97	2.65	7.76	98	2.44	7.10
12	3.00	.77	47	2.64	.70	41	2.43	2.33
21	2.99	2.27	78	2.64	.45	42	2.39	2.74
27	2.96	1.59	50	2.63	.74	44	2.39	2.22
85	2.90	1.28	70	2.62	.57	58	2.39	.86
90	2.88	2.02	51	2.61	2.01	52	2.35	1.12
Average	3.00	1.27	Average	2.64	1.64	Average	2.42	2.13
68	2.87	1.42	74	2.61	1.07	71	2.33	1.39
30	2.84	2.34	26	2.60	1.18	91	2.30	.81
29	2.82	1.61	54	2.60	.10	61	2.29	.20
6	2.80	.52	63	2.60	.94	48	2.25	1.17
60	2.80	.24	34	2.58	.99	24	2.18	.21
55	2.79	.88	56	2.58	.38	43	2.14	1.31
84	2.79	1.48	86	2.58	.90	36	1.99	1.13
22	2.77	.65	96	2.58	2.50	45	1.87	1.07
53	2.77	1.92	28	2.57	2.16	94	1.37	.79
75	2.77	.52	67	2.56	2.31	19	1.33	.47
Average	2.80	1.14	Average	2.59	1.25	Average	2.00	.85

TABLE VI.—*Nitrogen content and yield of grain from 180 wheat plants, arranged in inverse order of percentage of nitrogen, in groups of 10*—Continued.

SUMMARY OF AVERAGES.

Group No.	Groups from centgener No. 41801.		Groups from row No. 141801.		Group No.	Groups from centgener No. 41801.		Groups from row No. 141801.	
	Nitrogen.	Grain per plant.	Nitrogen.	Grain per plant.		Nitrogen.	Grain per plant.	Nitrogen.	Grain per plant.
	Per cent.	*Grams.*	*Per cent.*	*Grams.*		*Per cent.*	*Grams.*	*Per cent.*	*Grams.*
1	3.15	6.52	3.20	0.70	6	2.46	11.47	2.59	1.25
2	2.83	7.43	3.00	1.27	7	2.41	7.99	2.51	1.63
3	2.66	9.47	2.80	1.14	8	2.31	8.77	2.42	2.13
4	2.60	8.87	2.73	1.32	9	2.19	10.08	2.00	.85
5	2.52	9.41	2.64	1.64					

The fluctuation in yield between plants within a centgener or row commonly varies as much as 500 per cent. To note whether this wide variation bore any relation to nitrogen content, the results from all the plants in centgener No. 41801 and from its corresponding row were tabulated according to nitrogen content (Table VI). While the summary shows a marked variation in nitrogen content, there is no corresponding change in yield, although there is a slight irregular tendency for yield to increase as nitrogen decreases.

While the foregoing data deal almost entirely with variations under nursery conditions, it would be interesting to know whether such local variations also occur under field conditions. That individual plants vary in this way is without doubt true, as the records of the row plats just cited show. To determine whether local variations were found in field plats, two sets of data were secured in the following manner:

In one of the field plats a drill row 224 feet long was selected and divided into 2-foot sections. The soil was of average fertility and uniformity. The results are shown in Table VIII.

Also a plat of land 77 by 88 feet with a 5-foot margin outside of this was sown to Turkey winter wheat, using a drill 5.5 feet wide. A very uniform stand and quite uniform growth were secured. The plat would have yielded about 30 bushels per acre. At harvest time it was divided into blocks 5.5 feet square, making 224 such blocks. A composite sample was made from the harvest of each block and each sample was analyzed for total nitrogen. Figure 7 is a diagram of this plat, showing the yield of grain and percentage of nitrogen in each block. The same variation is here found that has been noted heretofore in the centgeners and nursery rows. For example, in the first series of 16 blocks, Nos. 2 and 13 average 1.74 per cent of nitrogen, while Nos. 3 and 8 average 2.07 per cent. This variation seems large in view of the fact that each block has an average of 600 to 800 plants. In this case the variation must be due to some local soil condition. When different numbers of blocks are grouped, the resulting areas are of considerable size, as illustrated by figure 8. The plats shown at *B* are 11 by 22 feet in area and each was sampled 8 times, yet they show a variation in nitrogen content ranging from 1.81 to 1.97 per cent.

REDUCING THE EXPERIMENTAL ERROR.

So great is the fluctuation in individual plants, due to variation in environment, that there would seem to be no hope of improving the percentage of nitrogen through the continuous selection of high fluctuates. No cumulative results can be expected where the error is larger than the expected variation.

1.80	1.83	2.00	1.91	1.90	1.89	1.79	1.75	2.03	1.83	2.18	1.93	1.77	1.86
224	208	192	176	160	144	128	112	96	80	64	48	32	16
1.80	2.07	1.77	1.90	1.70	1.79	1.90	2.04	1.95	1.83	2.06	1.76	1.86	1.79
223	207	191	175	159	143	127	111	95	79	63	47	31	15
1.93	1.96	1.83	1.92	1.69	1.90	1.80	1.89	1.83	1.85	2.00	2.13	1.82	1.83
222	206	190	174	158	142	126	110	94	78	62	46	30	14
1.89	1.96	1.92	1.86	1.79	1.86	1.79	1.94	1.92	1.80	1.97	2.00	1.87	1.73
221	205	189	173	157	141	125	109	93	77	61	45	29	13
2.00	2.01	1.89	1.77	1.97	1.85	1.97	2.10	1.99	1.83	2.00	1.92	1.79	1.89
220	204	188	172	156	140	124	108	92	76	60	44	28	12
1.96	1.96	2.00	1.82	1.93	1.82	1.87	1.87	1.92	1.99	1.87	1.83	1.92	1.96
219	203	187	171	155	139	123	107	91	75	59	43	27	11
1.89	2.11	1.99	1.87	1.86	1.84	2.06	1.90	1.90	1.82	1.81	1.97	1.79	1.89
218	202	186	170	154	138	122	106	90	74	58	42	26	10
2.03	1.86	1.80	1.86	2.06	1.72	1.86	1.72	2.07	1.82	1.84	1.97	1.96	2.01
217	201	185	169	153	137	121	105	89	73	57	41	25	9
1.83	1.82	1.82	1.75	1.77	1.72	1.90	1.83	1.90	1.83	1.90	1.85	1.76	2.07
216	200	184	168	152	136	120	104	88	72	56	40	24	8
1.87	2.14	1.96	1.87	1.97	1.90	1.90	2.13	1.80	1.83	1.90	2.06	1.94	1.87
215	199	183	167	151	135	119	103	87	71	55	39	23	7
1.90	1.94	1.94	1.77	1.89	1.86	1.82	1.87	1.80	1.84	1.87	2.04	1.94	1.89
214	198	182	166	150	134	118	102	86	70	54	38	22	6
1.94	1.76	1.96	1.99	1.87	2.04	1.93	1.77	1.74	1.89	1.93	1.96	2.04	1.97
213	197	181	165	149	133	117	101	85	69	53	37	21	5
1.83	1.99	1.97	2.08	1.99	1.96	2.15	1.82	1.78	1.83	1.98	1.89	1.85	1.87
212	196	180	164	148	132	116	100	84	68	52	36	20	4
1.85	1.87	1.85	1.82	1.92	1.89	2.13	1.82	1.73	1.83	1.96	2.04	1.86	2.00
211	195	179	163	147	131	115	99	83	67	51	35	19	3
2.10	1.83	1.85	1.96	2.01	1.92	1.68	1.89	1.85	1.85	1.83	1.85	2.07	1.75
210	194	178	162	146	130	114	98	82	66	50	34	18	2
1.93	1.86	1.93	1.87	1.90	1.86	1.99	1.89	1.83	1.82	1.96	1.99	1.99	2.06
209	193	177	161	145	129	113	97	81	65	49	33	17	1

FIG. 7.—Diagram of plat of Turkey wheat containing 224 blocks (each 5.5 feet square), showing the location of each block (lower figures) and variations in the percentage of nitrogen in the grain (upper figures).

The problem of finding a high-nitrogen wheat seems to resolve itself into the isolation of pure strains and the comparison of these for nitrogen content. To effect this isolation and comparison, a method must be found that will reduce error to the minimum. Replication according to some systematic method seems the most practical way. A number of examples have been worked up from data at hand to illustrate the effect of replication in reducing error.

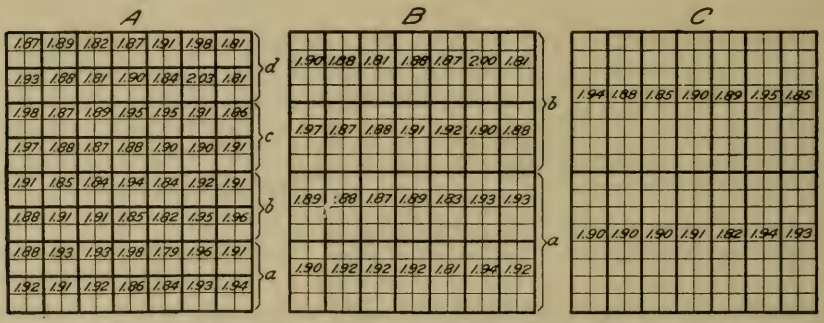

FIG. 8.—Diagrams of plats of Turkey wheat, showing the arrangement of 224 blocks (each 5.5 feet square) when combined in groups of adjacent blocks, with average nitrogen content for each group: *A*, Groups of 4; *B*, groups of 8; *C*, groups of 16.

REPLICATION OF SINGLE PLANTS.

In the first case the 840 centgener plants from the same parent, heretofore referred to (fig. 6), were grouped in various ways. Starting

with the first plant and taking every forty-second plant thereafter gave a composite group of 20 plants. Taking the second and every forty-second thereafter in the same way gave a second group, and so on in the same manner until 42 groups of 20 plants each had been made. In a similar manner 21 groups of 40 plants each were formed. Also, each of the 10 centgeners, being 10 plants square, was formed into 10 rows and the rows numbered 1 to 10. Each row would have 10 plants if the stand were perfect, but in this case it averaged only 8.4 plants per row. By combining the first rows, second rows, etc., in the 10 centgeners, 10 groups were made of 10 rows, or 84 plants each. The results of the above combinations are shown in Table VII. Where 20 plants, uniformly distributed, were combined, the variation in nitrogen content was from 2.40 to 2.67 per cent. Where 40 plants were combined, the variation ranged from 2.47 to 2.60 per cent, but the 10 groups of 10 rows each varied only from 2.49 to 2.59 per cent. Just what should constitute the limits of error in any case will depend on the minimum limit of the variations which are to be detected. In this case 0.1 per cent of nitrogen might be considered such a limit.

TABLE VII.—*Nitrogen content of 90 plants of Turkey wheat from 1 centgener and of 840 plants variously combined into groups to show deviation from mean.*

90 single plants in 1 centgener (united when having same nitrogen content).			840 single plants variously combined into groups.									
			Combination 1.—Four groups, each composed of every 42d plant in 10 centgeners, or 20 plants.				Combination 2.—Two groups, each composed of every 21st plant in 10 centgeners, or 40 plants.		Combination 3.—A group composed of every 10th row in 10 centgeners or 10 rows, equaling 84 plants.	
Nitrogen.	Frequency.	Deviation.	Nitrogen.	Deviation.	Nitrogen.	Deviation.	Nitrogen.	Deviation.	Nitrogen.	Deviation.
P. ct.			*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*	
2.09	1	−0.482	2.47	−0.043	2.44	−0.089	2.48	−0.044	2.49	−0.042
2.11	2	− .462	2.47	− .043	2.51	− .019	2.49	− .034	2.51	− .022
2.20	3	− .372	2.48	− .033	2.51	− .019	2.50	− .024	2.52	− .012
2.22	1	− .352	2.50	− .013	2.51	− .019	2.52	− .004	2.52	− .012
2.23	1	− .342	2.51	− .003	2.51	− .019	2.52	− .004	2.53	− .002
2.25	1	− .322	2.51	− .003	2.51	− .019	2.53	+ .006	2.53	− .002
2.26	1	− .312	2.53	+ .017	2.52	+ .009	2.53	+ .006	2.53	− .002
2.27	3	− .302	2.54	+ .027	2.59	+ .061	2.53	+ .006	2.54	+ .008
2.29	2	− .282	2.54	+ .027	2.59	+ .061	2.55	+ .036	2.56	+ .028
2.30	1	− .272	2.58	+ .067	2.60	+ .071	2.59	+ .066	2.59	+ .058
2.34	1	− .232								
2.36	1	− .212	2.513	.0276	2.529	.0386	2.524	.023	2.532	.0188
2.37	3	− .202								
2.39	3	− .182	2.46	− .092	2.40	− .128	2.47	− .07		
2.40	1	− .172	2.51	− .042	2.48	− .048	2.48	− .06		
2.41	2	− .162	2.52	− .032	2.50	− .028	2.48	− .06		
2.43	5	− .142	2.52	− .032	2.52	− .008	2.50	− .04		
2.44	1	− .132	2.54	− .012	2.53	+ .002	2.53	− .01		
2.46	3	− .112	2.54	− .012	2.54	+ .012	2.53	− .01		
2.47	4	− .102	2.54	− .012	2.54	+ .012	2.54	.00		
2.48	2	− .092	2.58	+ .028	2.56	+ .032	2.54	.00		
2.50	1	− .072	2.64	+ .088	2.56	+ .032	2.56	+ .02		
2.51	1	− .062	2.67	+ .118	2.57	+ .042	2.60	+ .06		
2.53	1	− .042			2.57	+ .042	2.61	+ .07		
2.56	1	− .012	2.572	.214	2.552	.0468	2.58	+ .052		
2.57	2	− .002								
							2.54	.0364		
					2.528	.0365				

Where the plants were repeated 20 and 40 times the error was almost what we might reasonably expect the actual variation in pure strains to be, but where 10 centgener rows, or 84 plants, were combined the extreme error was within bounds. The data would indicate that single plants would have to be replicated nearly 100 times to bring the variation within the limits of error.

REPLICATION OF 2-FOOT ROWS.

Table VIII illustrates the variation to be expected by replicating 2-foot rows. For these data a single 220-foot drill row in the general wheat field was divided into 2-foot sections and a composite sample made of each section. The sections were combined in two different ways. The first combination was composed of every twenty-second section, making 22 groups of 5 sections each, and the second combination was composed of every eleventh section, making 11 groups of 10 sections each.

Here, again, the extremes are rather wide, but if these are excluded the results would be called satisfactory. If a comparison of pure strains of wheat was being made under similar conditions, it would be necessary to take for further trial the entire best half of the strains tested in order to be within the limit of error. (See p. 30 and fig. 9.)

TABLE VIII.—*Nitrogen content of 110 2-foot sections of drill row of Turkey wheat, arranged in order of percentage of nitrogen and also in groups of 5 and 10, to show deviation from mean.*

Single 2-foot rows (those with same nitrogen content united).						Five rows in a group composed of every 22d row.		Ten rows in a group composed of every 11th row.	
Nitrogen.	Frequency.	Deviation.	Nitrogen.	Frequency.	Deviation.	Nitrogen.	Deviation.	Nitrogen.	Deviation.
Per cent.			*Per cent.*			*Per cent.*		*Per cent.*	
1.76	1	−0.271	2.04	5	+0.009	1.91	−0.109	1.96	−0.069
1.79	1	− .241	2.05	2	+ .019	1.96	− .059	1.98	− .049
1.81	1	− .221	2.06	4	+ .029	2.01	− .009	1.98	− .049
1.85	1	− .181	2.07	5	+ .039	2.01	− .009	2.00	− .029
1.86	2	− .171	2.08	4	+ .049	2.01	− .009	2.02	− .009
1.87	1	− .161	2.09	3	+ .059	2.02	+ .001	2.03	+ .001
1.88	1	− .151	2.10	6	+ .069	2.02	+ .001	2.04	+ .011
1.89	1	− .141	2.11	1	+ .079	2.03	+ .011	2.06	+ .031
1.90	1	− .131	2.12	2	+ .089	2.06	+ .041	2.06	+ .031
1.91	1	− .121	2.13	2	+ .099	2.09	+ .071	2.06	+ .031
1.92	7	− .111	2.14	3	+ .109	2.09	+ .071	2.13	+ .101
1.93	5	− .101	2.15	1	+ .119				
1.95	5	− .081	2.16	1	+ .129	2.019	.0355	2.029	.0374
1.96	3	− .071	2.17	1	+ .139				
1.97	2	− .061	2.19	2	+ .159	1.96	− .077		
1.98	5	− .051	2.20	3	+ .169	1.98	− .057		
1.99	2	− .041	2.26	4	+ .229	1.99	− .047		
2.00	4	− .031	2.28	1	+ .249	1.99	− .047		
2.01	7	− .021	2.37	1	+ .339	2.03	− .007		
2.02	2	− .011				2.03	− .007		
2.03	6	− .001	2.031		+ .093	2.04	+ .003		
						2.05	+ .013		
						2.08	+ .043		
						2.09	+ .053		
						2.17	+ .133		
						2.037	.0443		

REPLICATION OF 16-FOOT ROWS.

Since 16-foot rows are frequently used as test plats, a determination was made of the variation in a series of these. One hundred check plats from the 1909 field nursery were grouped by fives and tens in the same manner as in the two cases just cited. The results are shown in Table IX. The coefficient of variability and also the extreme variation are less than in the cases just considered.

TABLE IX.—*Nitrogen content of 100 16-foot rows of Turkey wheat, all from the same seed, arranged singly in order of percentage of nitrogen and also in groups of 5 and 10, to show deviation from mean.*

Single 16-foot rows (those with same nitrogen content united).						Five rows in a group composed of every 20th row.		Ten rows in a group composed of every 10th row.	
Nitrogen.	Frequency.	Deviation.	Nitrogen.	Frequency.	Deviation.	Nitrogen.	Deviation.	Nitrogen.	Deviation.
Per cent.			*Per cent.*			*Per cent.*		*Per cent.*	
1.82	1	−0.316	2.18	6	+0.044	2.09	−0.056	2.10	−0.037
1.86	2	− .276	2.20	1	+ .064	2.11	− .036	2.11	− .027
1.87	1	− .266	2.21	1	+ .074	2.13	− .016	2.12	− .017
1.89	1	− .246	2.22	4	+ .084	2.13	− .016	2.13	− .007
1.92	2	− .216	2.23	1	+ .094	2.13	− .016	2.14	+ .003
1.93	2	− .206	2.25	2	+ .114	2.14	− .006	2.14	+ .003
1.94	1	− .196	2.27	2	+ .134	2.16	+ .014	2.15	+ .013
1.96	3	− .176	2.28	2	+ .144	2.17	+ .024	2.15	+ .013
1.97	2	− .166	2.29	3	+ .154	2.19	+ .044	2.15	+ .013
1.99	1	− .146	2.31	3	+ .174	2.21	+ .064	2.18	+ .043
2.00	3	− .136	2.34	2	+ .204				
2.01	1	− .126	2.35	1	+ .214	2.146	.0292	2.137	.0176
2.03	5	− .106	2.36	1	+ .224				
2.04	3	− .096	2.38	1	+ .244	2.07	− .058		
2.06	6	− .076	2.42	1	+ .284	2.08	− .048		
2.07	2	− .066	2.43	1	+ .294	2.09	− .038		
2.08	6	− .056	2.45	1	+ .314	2.09	− .038		
2.10	3	− .036	2.48	1	+ .344	2.10	− .028		
2.11	2	− .026	2.50	1	+ .364	2.13	+ .002		
2.13	7	− .006	2.52	1	+ .384	2.17	+ .042		
2.14	2	+ .004				2.18	+ .052		
2.15	4	+ .014	2.136		.1178	2.18	+ .052		
2.17	4	+ .034				2.19	+ .062		
						2.128	.0420		

Where the 16-foot rows were repeated 10 times the extreme difference in nitrogen content was only 0.08 per cent. To further test this question, 500 rows, each 16 feet in length, were planted in the fall of 1909 under quite uniform conditions. These rows were harvested and combined in groups of 5, 10, 15, and 20, as in the previous case. The results are summarized at the bottom of Table X. When the rows are repeated only 5 times the error is too wide for satisfactory results, but when repeated 10 times the error is small enough for experimental purposes. Repeating 15 and 20 times gave only a small further reduction in variation.

A point of interest is the fact that in 1909, where rows were repeated 5 or 10 times, the experimental error was less than it was in 1910. In fact, there is no way of establishing a set rule as to the number of repetitions necessary, since the experimental error is influenced by

all the factors affecting the growth of plants, such as soil fertility, climate, or insects. In order to know what this error is in a particular case it would be advisable to grow a sufficient number of check plats in each system of plats to determine the error by actual test.

Table X is a summary of results with the systematic repetition of plants and rows. The column under "Coefficient of variability" shows that repeating 20 single plants in a systematic way has given about as great accuracy in determining nitrogen content as 2-foot rows repeated 10 times or 16-foot rows repeated 5 times. For determining comparative nitrogen content, repeating single plants 20 to 40 times in a systematic method seems to give quite satisfactory results.

TABLE X.—*Summary showing degree of error due to variation in environment, according to several methods of comparison.*

Classification.	Number of groups.	Mean nitrogen content.	Extreme variation.	Average deviation.	Standard deviation.	Coefficient of variability.
		Per cent.				*Per cent.*
90 single plants (Table VII)	90	2.572	2.09–3.44	0.2140	0.279	10.85
840 single plants (Table VII):						
Every 42d plant, 20 plants in a group	a 10	2.513	2.47–2.58	.0276	.0335	1.33
	b 10	2.552	2.46–2.67	.0468	.0592	2.32
	c 10	2.529	2.44–2.60	.0386	.0473	1.87
	d 12	2.528	2.40–2.58	.0365	.0484	1.91
Average	10.5	2.531	2.44–2.61	.0374	.0471	1.86
Every 21st plant, 40 plants in a group	a 10	2.524	2.48–2.59	.0230	.0307	1.22
	b 11	2.540	2.47–2.61	.0364	.0455	1.17
Average	10.5	2.532	2.47–2.60	.0297	.0381	1.50
As 10 centgeners, every 10th centgener row, 10 rows in a group	10	2.532	2.49–2.59	.0188	.0260	1.03
110 2-foot rows, single rows (Table VIII)	110	2.031	1.76–2.37	.093	.1087	5.35
Every 22d row, 5 rows in a group	a 11	2.019	1.91–2.09	.0355	.0499	2.47
	b 11	2.037	1.96–2.17	.0443	.0574	2.82
Average	11	2.028	1.94–2.13	.0399	.0537	2.65
Every 11th row, 10 rows in a group	11	2.029	1.96–2.13	.0374	.0464	2.28
100 16-foot rows (Table IX)	100	2.136	1.82–2.52	.1178	.1492	6.98
Every 20th row, 5 rows in a group	a 10	2.146	2.09–2.21	.0292	.0347	1.62
	b 10	2.128	2.07–2.19	.0420	.0451	2.12
Average	10	2.137	2.08–2.20	.0356	.0399	1.87
Every 10th row, 10 rows in a group	10	2.137	2.10–2.18	.0176	.0219	1.02
500 16-foot rows (in 1910):						
Single rows		1.905	1.68–2.28	.0859	.1080	5.67
Every 100th row, 5 rows in a group	a 25	1.904	1.81–1.99	.0393	.0469	2.46
	b 25	1.917	1.84–2.02	.0376	.0469	2.45
	c 25	1.908	1.81–2.03	.0403	.0502	2.63
	d 25	1.890	1.81–1.98	.0388	.0488	2.42
Average		1.905	1.82–2.00	.0379	.0474	2.49
Every 50th row, 10 rows in a group	a 25	1.908	1.83–1.96	.0273	.0329	1.72
	b 25	1.902	1.83–1.96	.0286	.0343	1.80
Every 33d row, 15 rows in a group		1.905	1.86–1.96	.0235	.0276	1.45
Every 25th row, 20 rows in a group		1.905	1.85–1.96	.0190	.0242	1.27

THE SMALL-BLOCK TEST.

Figure 7 (p. 22) illustrates the method of making the small-block test and also shows the percentage of nitrogen in the grain from each block. Table XI shows the result of repeating these blocks 4, 8, and 16 times in a systematic method, i. e., taking every fifty-sixth, twenty-eighth, or fourteenth block (fig. 8). The experimental error varied inversely with the number of repetitions, but was only within the limit of error when the repetition was 16 times.

TABLE XI.—*Nitrogen content of Turkey wheat grown in 224 block plats (each 5.5 feet square) in 1909 and 1910.*

SYSTEMATICALLY REPEATED TO FORM GROUPS OF 4, 8, AND 16 BLOCKS.

Four blocks in a group composed of every 56th block.				Eight blocks in a group composed of every 28th block.		Sixteen blocks in a group composed of every 14th block.	
Nitrogen.	Deviation.	Nitrogen.	Deviation.	Nitrogen.	Deviation.	Nitrogen.	Deviation.
Per cent.		*Per cent.*		*Per cent.*		*Per cent.*	
1.78	−0.128	1.81	−0.115	1.82	−0.096	1.84	−0.06
1.84	− .068	1.85	− .075	1.87	− .046	1.86	− .04
1.85	− .058	1.87	− .055	1.88	− .036	1.87	− .03
1.88	− .028	1.87	− .055	1.90	− .016	1.87	− .03
1.89	− .018	1.90	− .025	1.90	− .016	1.89	− .01
1.90	− .008	1.93	+ .005	1.90	− .016	1.90	+ .00
1.91	+ .002	1.93	+ .005	1.92	+ .004	1.90	+ .00
1.91	+ .002	1.96	+ .035	1.92	+ .004	1.91	+ .01
1.93	+ .022	1.96	+ .035	1.94	+ .024	1.91	+ .01
1.93	+ .022	1.96	+ .035	1.94	+ .024	1.92	+ .02
1.94	+ .032	1.96	+ .035	1.94	+ .024	1.92	+ .02
1.95	+ .042	1.97	+ .045	1.95	+ .034	1.93	+ .03
1.98	+ .072	1.97	+ .045	1.95	+ .034	1.94	+ .04
2.02	+ .112	2.01	+ .085	1.99	+ .074	1.94	+ .04
Av'ge..1.908	.0439	1.925	.0464	1.916	.032	1.90	.024
1.83	− .041	1.80	− .094	1.83	− .051		
1.83	− .041	1.86	− .034	1.85	− .031		
1.83	− .041	1.87	− .024	1.86	− .021		
1.84	− .031	1.87	− .024	1.86	− .021		
1.84	− .031	1.87	− .024	1.86	− .021		
1.85	− .021	1.88	− .014	1.87	− .011		
1.85	− .021	1.89	− .004	1.88	− .001		
1.86	− .011	1.90	+ .006	1.88	− .001		
1.87	− .001	1.90	+ .006	1.88	− .001		
1.87	− .001	1.90	+ .006	1.89	+ .011		
1.88	+ .009	1.90	+ .006	1.90	+ .021		
1.94	+ .069	1.90	+ .006	1.92	+ .041		
1.95	+ .079	1.94	+ .046	1.92	+ .041		
1.95	+ .079	2.04	+ .146	1.93	+ .051		
Av'ge..1.871	.034	1.894	.0314	1.881	.0231		

TABLE XI.—*Nitrogen content of Turkey wheat grown in 224 block plats (each 5.5 feet square) in 1909 and 1910*—Continued.

COMBINED IN GROUPS OF 4, 8, AND 16 ADJACENT BLOCKS, TO SHOW THE EFFECT OF SIZE OF PLAT ON VARIABILITY.

Four sets of 14 groups, with 4 adjacent blocks in each group.						Two sets of 14 groups, with 8 adjacent blocks in each group.			One set of 14 groups, with 16 adjacent blocks in each group.		
Nitrogen.	Deviation.	Standard deviation.	Nitrogen.	Deviation.	Standard deviation.	Nitrogen.	Deviation.	Standard deviation.	Nitrogen.	Deviation.	Standard deviation.
Per cent.			*Per ct.*			*Per ct.*			*Per ct.*		
1.79	−0.117	.....	1.86	−0.05	.....	1.81	−0.086	.....	1.82	−0.077	.....
1.84	− .067	.....	1.87	− .04	.....	1.83	− .066	.....	1.85	− .047	.....
1.86	− .047	.....	1.87	− .04	.....	1.87	− .026	.....	1.85	− .047	.....
1.88	− .027	.....	1.88	− .03	.....	1.88	− .016	.....	1.88	− .017	.....
1.91	+ .003	.....	1.88	− .03	.....	1.89	− .006	.....	1.89	− .007	.....
1.91	+ .003	.....	1.89	− .02	.....	1.89	− .006	.....	1.90	+ .003	.....
1.92	+ .013	.....	1.90	− .01	.....	1.90	+ .004	.....	1.90	+ .003	.....
1.92	+ .013	.....	1.90	− .01	.....	1.92	+ .024	.....	1.90	+ .003	.....
1.93	+ .023	.....	1.91	0	.....	1.92	+ .024	.....	1.90	+ .003	.....
1.93	+ .023	.....	1.91	0	.....	1.92	+ .024	.....	1.91	+ .013	.....
1.93	+ .023	.....	1.95	+ .04	.....	1.92	+ .024	.....	1.93	+ .033	.....
1.94	+ .033	.....	1.95	+ .04	.....	1.93	+ .034	.....	1.94	+ .043	.....
1.96	+ .053	.....	1.97	+ .06	.....	1.93	+ .034	.....	1.94	+ .043	.....
1.98	+ .073	.....	1.98	+ .07	.....	1.94	+ .044	.....	1.95	+ .053	.....
Average..1.907	.037	0.048	1.91	.0314	0.0376	1.896	.0299	0.0372	1.897	.028	0.0363
1.82	− .072	.....	.....	.....	.....	1.81	− .081	.....			
1.84	− .052	.....	1.81	− .072	.....	1.81	− .081	.....			
1.84	− .052	.....	1.81	− .072	.....	1.87	− .021	.....			
1.85	− .042	.....	1.81	− .072	.....	1.87	− .021	.....			
1.85	− .042	.....	1.82	− .062	.....	1.88	− .011	.....			
1.88	− .012	.....	1.84	− .042	.....	1.88	− .011	.....			
.....	.....	.....	1.87	− .012	.....	.....	.....	.....			
1.91	+ .018	.....	1.87	− .012	.....	1.88	− .011	.....			
1.91	+ .018	.....	1.88	− .002	.....	1.88	− .011	.....			
1.91	+ .018	.....	1.89	+ .008	.....	1.90	+ .009	.....			
1.91	+ .018	.....	1.90	+ .018	.....	1.90	+ .009	.....			
1.92	+ .028	.....	1.91	+ .028	.....	1.91	+ .019	.....			
1.94	+ .048	.....	1.93	+ .048	.....	1.92	+ .029	.....			
1.95	+ .058	.....	1.98	+ .098	.....	1.97	+ .079	.....			
1.96	+ .068	.....	2.03	+ .148	.....	2.00	+ .109	.....			
Average..1.892	.0390	.0436	1.882	.0496	.0636	1.891	.0358	.0492			

TABLE XI.—*Nitrogen content of Turkey wheat grown in 224 block plats (each 5.5 feet square) in 1909 and 1910*—Continued.

SUMMARY SHOWING EXPERIMENTAL ERROR WHEN BLOCKS ARE ASSEMBLED IN VARIOUS WAYS..

Classification.	Number of groups.	Season of 1909.					Season of 1910.				
		Mean nitrogen content.	Extreme variation.	Average deviation.	Standard deviation.	Coefficient of variability.	Mean nitrogen content.	Extreme variation.	Average deviation.	Standard deviation.	Coefficient of variability.
		P. ct.				*P. ct.*	*P. ct.*				*P. ct.*
Systematically repeated..	1	1.898	1.68–2.18	0.0786	0.0981	5.17	1.866	1.66–2.24	0.0692	0.8987	4.81
Every 56th block, 4 blocks in a group...	a 14	1.908	1.78–2.02	.0439	.0579	3.03	1.852	1.81–1.89	.0250	.0278	1.50
	b 14	1.871	1.83–1.95	.0340	.0425	2.27	1.850	1.79–1.91	.0300	.0342	1.85
	c 14	1.925	1.81–2.01	.0464	.0546	2.84	1.871	1.81–1.92	.0259	.0316	1.69
	d 14	1.894	1.80–2.04	.0314	.0503	2.61	1.885	1.82–2.04	.0386	.0532	2.82
Average.....	14	1.90	1.80–2.00	.0389	.0513	2.69	1.865	1.81–1.94	.0299	.0347	1.96
Every 28th block, 8 blocks in a group...	a 14	1.916	1.82–1.99	.0320	.0438	2.29	1.863	1.83–1.89	.0143	.0167	.89
	b 14	1.881	1.83–1.93	.0231	.0287	1.53	1.869	1.83–1.91	.0184	.0226	1.21
Average.....	14	1.90	1.82–1.96	.0275	.0362	1.91	1.866	1.83–1.90	.0163	.0196	1.05
Every 14th block, 16 blocks in a group...	14	1.90	1.84–1.94	.0240	.0295	1.55	1.864	1.84–1.88	.0123	.013[illegible]	.72
Adjacent groups: Four blocks in a group	a 14	1.907	1.79–1.98	.0370	.0480	2.52	1.929	1.80–2.02	.0503	.0612	3.17
	b 14	1.892	1.82–1.96	.0390	.0436	2.31	1.871	1.79–1.96	.0400	.0484	2.59
	c 14	1.910	1.86–1.98	.0314	.0376	1.93	1.841	1.78–1.92	.0301	.0368	2.00
	d 14	1.882	1.81–2.03	.0496	.0636	3.31	1.817	1.77–1.89	.0261	.0319	1.76
Average.....	14	1.894	1.82–1.99	.0442	.0482	2.54	1.865	1.78–1.95	.0366	.0456	2.38
Eight blocks in a group	a 14	1.896	1.81–1.94	.0299	.0372	1.96	1.901	1.82–1.98	.0444	.0504	2.65
	b 14	1.891	1.81–2.00	.0358	.0492	2.60	1.829	1.79–1.89	.0263	.0299	1.63
Average.....	14	1.894	1.81–1.97	.0328	.0432	2.28	1.865	1.80–1.93	.0353	.0401	2.14
Sixteen blocks in a group.....	14	1.897	1.82–1.95	.028	.0363	1.91	1.866	1.80–1.96	.0403	.0464	2.49

In 1910 the same set of blocks was again in wheat, and they were again grouped in the same way, exactly the same plats being combined each year. The experimental error was less in 1910 than in 1909, and repeating the blocks 8 times gave total variations ranging from 1.83 to 1.90 per cent, which is well within the experimental limit. It appears that repeating the plats in this particular case 8 times in 1910 gave as good results as repeating 16 times in 1909; in fact, repeating 4 times would have been almost as satisfactory. In the case of the 16-foot rows just described the error was least in 1909, while the reverse was true in regard to the error in the blocks. This result again illustrates the point, made in discussing the row tests, that sufficient check plats must be used in order to know the experimental error in any particular case.

INCREASING THE SIZE OF PLAT.

Table XI also illustrates the effect of increasing the size of the plat. While such increase ought theoretically to reduce error from the standpoint of increasing the number of plants and including a larger

number of local soil variations, yet an equal number of large plats reach over into new territory and include new causes for variation. To secure a practical illustration the 224 small blocks were combined into several series of larger plats by adding together adjacent plats. This method is illustrated in figure 8 (p. 22), and the statistical data are given in Table XI, a study of which shows that increasing the size above four adjacent blocks does not decrease the variability. In comparing systematic replication (Table X) with increase in size of plat it will be seen that the former constantly decreases variation, and would so continue to infinity, while the latter would not be controlled by such a law. It has been noted that the degree of variability was not the same when similar data were collected from different fields or in different years.

Variation is not a constant factor even where conditions are quite uniform, as is illustrated by the four sets of 14 groups composed of four adjacent plats. The fluctuation of extremes is almost twice as great in the fourth set as in the third.

The foregoing data can not be taken as a strict comparison of the different methods, as the data in each case were secured under somewhat different conditions. They are mainly valuable in illustrating the expected variation when different methods of comparison are used. It is evident that, whatever the method used, a single plat or duplicate plats can not be relied on for determining the actual nitrogen content of a strain or variety of wheat. The plats must be repeated 5 to 15 times, depending on uniformity of conditions and accuracy of results desired. In addition, at least a few series of check plats should be included in order to determine the experimental error as a guide to accuracy of results.

Our experience so far indicates that the simplest and most accurate method is to use 16-foot rows, replicated 10 times, with a check plat every 5 or 10 rows.

THE LIMIT OF EXPERIMENTAL ERROR.

The above examples give some indication of the experimental error to be expected by the different methods. Since the experimental error depends upon the variation in environmental conditions, it is possible that conditions might be found so ideal that there would be practically no experimental error; also that under other conditions it might be greater than in the cases just cited. In all cases the experimental error should be determined by the use of check plats. With this factor known it will be possible to decide on some plan of selection. Figure 9 illustrates an ideal case where the experimental error is known. Suppose that in 10 strains of wheat being tested by the row method with check plats, the highest should

average 3 per cent of nitrogen and the lowest 2 per cent of nitrogen, the remainder being distributed between. Suppose a series of checks, repeated in the same way as the tested strains, showed a variation of 2.2 per cent to 2.6 per cent, with a mean of 2.4 per cent. This would give an experimental error of 0.2 per cent; that is, a certain strain might be 0.2 per cent higher than it should be or 0.2 per cent lower than it should be. Let the line *ab* indicate the variation in nitrogen content obtained in the 10 strains under test. If the experimental error equaled 0.2 per cent, then No. 1 might equal either 3.2 per cent or 2.8 per cent, and in the same way a strain analyzing 2.6 per cent might possibly be either 2.8 per cent or 2.4 per cent. In other words, the strain analyzing 2.6 per cent might be just as good as the one analyzing 3 per cent. Therefore, if the experimental error has been determined, the rule would be to double the error and subtract this sum from the highest variant. The remainder after subtraction would represent the nitrogen content below which all strains could be discarded without danger of discarding a high-nitrogen strain. (The same method applies to the use of experimental error in selecting for yield.) In the case illustrated in figure 9, all strains analyzing above 2.6 per cent must be selected for further test to be sure that one of the best is not being left. If the experimental error equals one-half the real variations in strains compared, then no selection can be made, but all the strains must be retested.

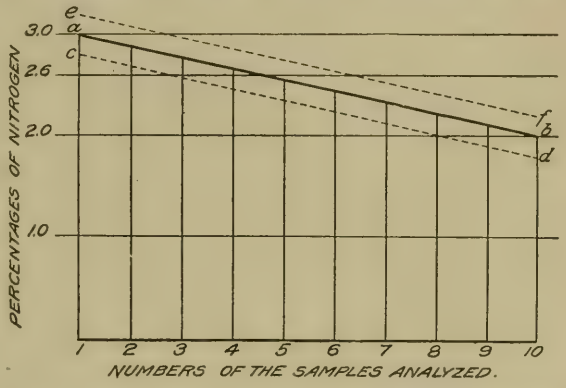

FIG. 9.—Diagram showing the method of selection for nitrogen content when the experimental error is known.

SUMMARY.

(1) Wheat plants growing under field conditions or nursery conditions show great variation in nitrogen content. This variation, however, does not seem to be inherited but is apparently due to local variation in environment and is therefore not capable of transmission.

(2) Centgeners, rows, and small plats vary almost as much as individual plants, owing to local variation in environment.

(3) The most practical way of overcoming this variation is by replicating the plats a sufficient number of times to reduce the error to less than one-half the real variation.

(4) To bring the experimental error within proper bounds, single plants should be repeated 40 or more times, 16-foot rows 5 to 10 times, and blocks 5.5 feet square 8 to 16 times. No data are given for centgeners, but the variation in centgeners is about the same as in the blocks.

(5) In order to eliminate the undesirable strains, the experimental error must be less than one-half the real or expected variation.

(6) The easiest and most practical method of growing strains to compare for nitrogen content is to plant in rows 12 to 16 feet in length and repeat 10 times in different parts of the field. Several series of check plats should also be inserted.

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II.—EXPERIMENTAL ERROR IN THE NURSERY AND VARIATION IN YIELD

INTRODUCTION.

A very large share of cereal breeding to-day consists in the separation of pure strains from what we call our ordinary varieties of cereals. In dealing with new hybrids the separation involves the selection of the most desirable strains after types have been fixed. We are mainly concerned for the present in finding the best-yielding strains. This necessitates the finding of a method by which comparative field tests can be made rapidly in large numbers.

The method of comparing strains in "centgeners" first came into general use some 10 years ago, and later the "row" method was evolved. At present the Nebraska Agricultural Experiment Station is experimenting with a small block similar in size to the centgener, but sown at the ordinary rate of seeding.

A number of sources of error in all these methods are due to unexpected variations in soil and climate. It is the purpose of this paper to discuss some of these sources of error and to suggest methods of correction.

VARIATION IN YIELD FROM CHECK ROWS.

In our row-breeding work we use every fifth row as a check plat. All check plats are from the same seed and sown in the same way. A great variation is found in these check rows even when conditions appear quite uniform. Table XII shows the yield of 47 consecutive check rows in one of the 1909 series. These rows were 14 feet long and each was hand planted with 400 seeds of Turkey wheat. They were not quite as uniform as we sometimes have them, owing to dry weather in the spring, although the appearance of the plats was uniform enough at harvest time. One object in presenting the data here, however, is to illustrate the effect of repeating check plats on correction of error. All things being equal, the yields of the 47 plats should have been the same. But all factors can never be equal, so in row-breeding work, owing to unequal environment, we must expect a wide degree of error. The only practical way so far suggested to overcome this error is to repeat the plats, according to some systematic method, enough times to equalize variations in soil or climatic effects. If the plats are repeated only a few times there is

still danger of a large error due to the chance combination of plats unduly high or low. This is illustrated by data given in the lower half of Table XII, where all the above check rows have been brought together in groups of six each (except group *h*), taking every eighth plat to form a group, to show the chance of error in repeating a series of strains six times.

TABLE XII.—*Yield of 47 14-foot check plats of Turkey wheat in 1909.*

CHECK PLATS IN CONSECUTIVE ORDER.

Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
205	239	162	165	182	205	216	230
170	240	204	279	265	270	278	310
202	167	200	238	285	265	222	238
247	216	225	284	255	265	279	155
304	272	226	237	245	150	268	186
209	310	278	347	168	306	239	

CHECK PLATS SYSTEMATICALLY REPEATED TO FORM EIGHT GROUPS.

Group *a*.	Group *b*.	Group *c*.	Group *d*.	Group *e*.	Group *f*.	Group *g*.	Group *h*.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
205	170	202	247	304	209	239	240
167	216	272	310	162	204	200	225
226	278	165	280	238	284	237	347
182	265	285	255	245	168	205	270
265	265	150	306	216	278	222	280
268	239	230	310	238	155	186	.....
219	239	217	285	234	216	215	272

Groups arranged in order of average yield of included plats: *g*, 215; *f*, 216; *c*, 217; *a*, 219; *e*, 234; *b*, 239; *h*, 272; *d*, 285. Average, 237.

Groups *a* and *d* illustrate the chance grouping of high-yielding and low-yielding plats. With only 5 plats out of the 47 yielding above 300 grams, three of them by chance fell into group *d* while a number below normal fell into group *a*. The average yields of the 8 groups varied from 215 grams to 285 grams. This variation indicates the amount of experimental error to be expected under similar conditions. Since the experimental error is larger than the real variation expected in different strains of wheat, results obtained under such circumstances would not be reliable. Until our system of testing will show actual differences of 10 per cent in yield, it can not be of much value in comparing the yielding value of different strains.

VARIATION IN YIELD FROM REPEATED ROWS.

In order to make a more careful test of the accuracy of replicating row tests, 100 rows of Kherson oats were planted, each row being 12.5 feet in length and containing 500 seeds. The plat chosen for this test was quite uniform and the appearance of the plat at harvest was very satisfactory. Three-fourths of the rows yielded from 225 to 275 grams each, with a few much higher and a few very low. Table XIII shows these rows arranged in consecutive order as they were

in the nursery, with the yield of each row and the average yield of groups of five adjacent rows.

We may get some idea of how replication corrects error by assembling these rows into series as in the comparative test of strains. These data are shown and also summarized in Table XIII. In series 1 the yields of 5 adjacent rows are averaged (as rows 1 to 5, 6 to 10, etc.). In series 2 every twentieth row is taken (as rows 1–21–41–61–81, etc.) and averaged. In series 3 every tenth row is taken, making 10 repetitions; and in series 4 every fifth row, making 20 repetitions.

TABLE XIII.—*Yield of thrashed grain from 100 rows of Kherson oats.*

BY ROWS AND GROUPS OF FIVE ADJACENT ROWS IN CONSECUTIVE ORDER.

Row No.	Yield of grain.		Row No.	Yield of grain.		Row No.	Yield of grain.		Row No.	Yield of grain.	
	Actual.	Mean of 5 rows.		Actual.	Mean of 5 rows.		Actual.	Mean of 5 rows.		Actual.	Mean of 5 rows.
	Grams.	*Grams.*		*Grams.*	*Grams.*		*Grams.*	*Grams.*		*Grams.*	*Grams.*
1	228		26	252		51	244		76	233	
2	273		27	248		52	261		77	247	
3	255	236	28	206	246	53	258	250	78	211	225
4	224		29	280		54	244		79	237	
5	204		30	247		55	245		80	200	
6	205		31	257		56	248		81	248	
7	230		32	240		57	229		82	200	
8	260	224	33	233	235	58	211	221	83	227	222
9	195		34	230		59	227		84	220	
10	233		35	217		60	188		85	214	
11	257		36	226		61	248		86	184	
12	243		37	190		62	257		87	233	
13	250	248	38	222	220	63	270	263	88	244	234
14	230		39	261		64	264		89	241	
15	261		40	200		65	275		90	270	
16	235		41	246		66	300		91	241	
17	273		42	249		67	151		92	174	
18	273	255	43	276	254	68	153	216	93	247	242
19	263		44	237		69	205		94	266	
20	230		45	261		70	272		95	281	
21	244		46	267		71	194		96	240	
22	245		47	259		72	274		97	232	
23	209	234	48	252	249	73	242	235	98	228	247
24	247		49	251		74	235		99	290	
25	224		50	218		75	229		100	245	

SYSTEMATICALLY GROUPED IN VARIOUS WAYS TO SHOW EFFECT OF REPLICATION ON REDUCTION OF VARIATION IN YIELD.

Series 1.—Groups of 5 adjacent rows.		Series 2.—Groups of 5 rows, taking every 20th row.		Series 3.—Groups of 10 rows, taking every 10th row.		Series 4.—Groups of 20 rows, taking every 5th row.	
Yield.	Deviation.	Yield.	Deviation.	Yield.	Deviation.	Yield.	Deviation.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
216	−21.8	212	−25.8	239	+ 1.2	226	−11.8	234	−3.8
220	−17.8	223	−14.8	231	+ 3.2	229	− 8.8	235	−2.8
221	−16.8	224	−13.8	242	+ 4.2	230	− 7.8	238	+ .2
222	−15.8	229	− 8.8	242	+ 4.2	237	− .8	241	+3.2
224	−13.8	234	− 3.8	243	+ 5.2	238	+ .2	241	+3.2
225	−12.8	234	− 3.8	246	+ 8.2	239	+ 1.2		
234	− 3.8	234	− 3.8	246	+ 8.2	241	+ 3.2		
234	− 3.8	236	− 1.8	248	+10.2	243	+ 5.2		
235	− 2.8	237	− .8	245	+17.2	245	+ 7.2		
235	− 2.8	238	+ .2	256	+18.2	250	+12.2		
Average...	237.8	11.4	.....	.....	237.8	7.9	237.8	5.8	237.8	2.6

TABLE XIII.— *Yield of thrashed grain from 100 rows of Kherson oats*—Continued.

SUMMARY SHOWING COMPARISON OF GROUPINGS.

Number of rows in a group.	Average deviation from mean yield when rows are—		Coefficient of variability when rows are—		Variation of extremes in yield when rows are—	
	Adjacent.	Distributed.	Adjacent.	Distributed.	Adjacent.	Distributed.
	Grams.	*Grams.*	*Per cent.*	*Per cent.*	*Grams.*	*Grams.*
1	21.26	21.26	11.5	11.5	151 to 300	151 to 300
5	11.38	7.87	5.50	4.8	216 to 263	212 to 256
10	7.60	5.84	3.66	3.0	227 to 251	226 to 250
20	3.46	2.60	1.56	1.7	234 to 243	234 to 241

There is less variation when the five rows are distributed throughout the plat than when adjacent; also the variation decreases as the number of repetitions increases. Evidently in the case under consideration it would be necessary to repeat about 20 times in order to obtain comparable data.

To secure more data on this point, 500 row plats of Turkey wheat were planted in the autumn of 1909. The rows were each 16 feet in length, all planted uniformly and with the same seed in soil of average fertility and in good tilth. At harvest the rows appeared to be uniform in character and would have yielded about 30 bushels to the acre. Table XIV summarizes the results.

TABLE XIV.— *Yield of grain from 500 16-foot rows of Turkey wheat, systematically repeated in various ways to show experimental error.*

Classification.	Number of groups.	Mean yield.	Extreme variation.	Average deviation.	Standard deviation.	Coefficient of variability.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Per cent.*
Single rows	500	250.7	156 –403	28.67	35.85	14.34
Every 100th row, 5 rows in a group	a 25	242.0	219.6–277.8	13.3	15.76	6.51
	b 25	256.0	233.6–281.4	11.7	14.11	5.51
	c 25	247.3	226.4–272.6	11.9	13.03	5.27
	d 25	256.6	228.4–282.4	11.8	14.85	5.79
Average		250.5	227.0–278.5	12.17	14.44	5.77
Every 50th row, 10 rows in a group	a 25	245.1	224.1–270.7	10	12.18	4.97
	b 25	256.3	242.0–276.6	8	9.69	3.78
Average		250.7	233.0–273.6	9	10.93	4.37
Every 33d row, 15 rows in a group	33	250.2	235.5–273.9	6.2	7.95	3.18
Every 25th row, 20 rows in a group	25	250.7	234.3–269.6	7.4	9.28	3.70

In this case the experimental error was much higher than with the 100 rows of oats (Table XIII) and did not reduce so rapidly by repetition. This may be due to the fact that the 500 rows of wheat covered a greater area than the 100 rows of oats, thus having more causes for variation. It is probable that the greater the number of strains to be compared the more replications will be necessary

because of the larger area they will cover. However, when repeated 15 times, the average deviation is about half as much as when repeated 5 times, but replicating 20 times did not make a further improvement. It will be seen that the extreme variation is rather wide. It would be impossible to make a direct comparison of yield between strains or varieties tested under conditions where the variation of extremes is so large. It would be necessary in such case to select a rather large percentage of the high-yielding varieties and continue the test with them for some years. The method of selection will be hereafter explained.

WEST

671 209	657 210	703 211	755 212	760 213	686 214	592 215	739 216	732 217	710 218	753 219	680 220	680 221	677 222	795 223	723 224
658 193	713 194	613 195	632 196	667 197	645 198	660 199	768 200	786 201	768 202	666 203	843 204	795 205	763 206	716 207	741 208
657 177	671 178	623 179	715 180	543 181	613 182	640 183	798 184	759 185	764 186	995 187	793 188	936 189	755 190	792 191	838 192
642 161	680 162	654 163	673 164	760 165	709 166	682 167	724 168	774 169	860 170	787 171	725 172	664 173	851 174	690 175	770 176
735 145	580 146	620 147	675 148	765 149	742 150	772 151	698 152	652 153	661 154	768 155	777 156	745 157	768 158	851 159	719 160
575 129	598 130	705 131	642 132	704 133	643 134	650 135	572 136	752 137	740 138	863 139	680 140	722 141	723 142	703 143	756 144
727 113	633 114	615 115	685 116	662 117	639 118	657 119	608 120	620 121	624 122	745 123	764 124	703 125	752 126	788 127	682 128
572 97	573 98	560 99	645 100	692 101	644 102	632 103	574 104	606 105	648 106	806 107	791 108	629 109	650 110	679 111	588 112
580 81	425 82	732 83	730 84	706 85	732 86	736 87	655 88	673 89	793 90	765 91	576 92	609 93	568 94	728 95	620 96
588 65	526 66	596 67	777 68	776 69	779 70	721 71	728 72	604 73	742 74	665 75	621 76	611 77	623 78	646 79	617 80
617 49	683 50	726 51	835 52	668 53	664 54	691 55	770 56	775 57	685 58	723 59	583 60	580 61	395 62	511 63	653 64
602 33	662 34	640 35	700 36	650 37	655 38	563 39	600 40	730 41	690 42	713 43	530 44	568 45	410 46	478 47	636 48
665 17	736 18	630 19	598 20	895 21	592 22	593 23	659 24	718 25	705 26	667 27	585 28	560 29	655 30	633 31	733 32
609 1	706 2	790 3	678 4	695 5	715 6	622 7	658 8	597 9	632 10	713 11	585 12	657 13	495 14	618 15	652 16

EAST

FIG. 10.—Diagram of plats of Turkey wheat, showing the arrangement of 224 blocks (each 5.5 feet square) and the yield of grain (in grams) for each block.

VARIATION IN YIELD FROM SMALL BLOCKS.

For this experiment 224 blocks, each 5.5 feet square, were laid out in a plat 14 blocks one way by 16 the other. The blocks were all sown to Turkey winter wheat in the fall of 1908. To sow these the drill, 5.5 feet wide, was driven straight across the first series of 14 blocks, the boundaries of the blocks being later established. Each series was sown in the same way and no path or space was allowed between the blocks. Figure 10 is a diagram of the blocks, the yield in grams being marked in each block. A large variation in yield was found in the different blocks, amounting to 100 per

cent in the extreme cases, although the appearance at harvest time was fairly uniform. These plats have been combined in various ways in order to study the yields. The results are shown in Table XV.

EFFECT OF REPETITION IN REDUCING ERROR.

The first part of Table XV shows the 224 blocks combined in various ways, namely, 56 groups of 4 blocks each when every fifty-sixth block was taken, 28 groups of 8 blocks each when every twenty-eighth block was taken, and 14 groups of 16 blocks each when every fourteenth block was taken. The 56 groups of 4 blocks each were divided into 4 sets of 14 each and the 28 groups of 8 into 2 sets of 14 each. This division into sets was for the purpose of having an equal number of blocks for comparison in each case. We find illustrations of a combination of high-yielding plats and low-yielding plats such as were noted in Table XII. For example,

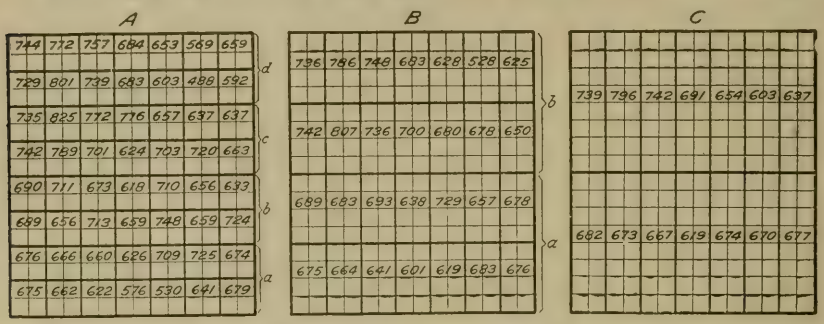

FIG. 11.—Diagrams of plats of Turkey wheat, showing the arrangement of 224 blocks (each 5.5 feet square) when combined in groups of adjacent blocks, with the average yield for each group: *A*, Groups of 4; *B*, groups of 8; *C*, groups of 16.

when the blocks are repeated 4 times the range in yield varies from an average of 595.2 grams per block to an average of 786.5 grams per block, a difference of 32 per cent. If varieties were being tested by the same system, this variation would be more than we might expect in the yields of different kinds.

When the blocks are repeated 8 times the average variation ranges from 627.5 to 717.8 grams, a difference of 90 grams, or 14 per cent. By repeating 16 times the extreme variation is reduced to 47 grams, or 7 per cent. However, with the exception of the extremes, the variation here is small. The question now to consider is the minimum number of blocks which will insure comparable results. If comparable results are to be secured the first season, the blocks should be repeated 15 to 20 times. If it were desirable to carry the strains for a period of 3 years, repeating 8 to 10 times would probably be sufficient, since this would give a total of 24 to 30 blocks for the 3 years.

RELATION OF SIZE OF PLAT TO VARIATION.

It is very desirable in plant-breeding work to determine the minimum size of plat that it is practicable to use, since with hundreds of strains to try each year it would be impossible to handle them in large plats. Taking the above series of 224 small blocks, the adjacent blocks could be combined to give a continuous series of larger and larger blocks. Figure 11 shows how these combinations were made and Table XV gives statistical results, showing also in a summary for two years the comparative effect of increasing the size of the block and of repeating small blocks.

TABLE XV.— *Yield of Turkey wheat grown in 224 block plats (each 5.5 feet square) in 1909 and 1910.*

SYSTEMATICALLY REPEATED TO FORM GROUPS OF 4, 8, AND 16 BLOCKS.

Classification.	Number in group.	Season of 1909.					Season of 1910.				
		Mean yield per block.	Extreme variations.	Average deviation.	Standard deviation.	Coefficient of variability.	Mean yield per block.	Extreme variations.	Average deviation.	Standard deviation.	Coefficient of variability.
						P. ct.					*P. ct.*
Single blocks	224	680.38	373 –995	67.23	81.98	13	463.71	300 –809	47.62	62.62	13.50
Every 56th block, 4 blocks in a group.	a 14	668.82	613.25–721.25	29.33	35.79	5.35	468.23	441.75–502.75	15.80	17.88	3.82
	b 14	689.96	645.75–786.50	32.99	39.80	5.77	467.09	412.25–504.25	15.36	21.87	4.68
	c 14	680.95	595.25–728.00	21.71	30.09	4.42	450.59	397.50–490.50	21.52	26.34	5.84
	d 14	683.36	627 –744.75	24.36	32.09	4.69	468.93	403.75–581.50	35.12	44.23	9.43
Average		680.77	620.32–745.12	27.09	34.44	5.05	463.71	413.81–515.80	21.95	27.58	5.94
Every 28th block, 8 blocks in a group.	a 14	674.20	627.50–704.88	18.04	21.63	3.21	459.41	441.38–472.50	8.46	9.65	2.10
	b 14	686.66	660.38–717.88	16.45	18.62	2.71	468.01	433.38–515.38	15.28	19.34	4.13
Average		680.43	643.94–211.38	17.25	20.13	2.96	463.71	437.38–493.94	11.87	14.43	3.11
Every 14th block, 16 blocks in a group.	14	680.43	653.25–700.38	7.24	10.41	1.53	463.72	450.86–490.56	6.47	9.60	2.07

COMBINED IN GROUPS OF 4, 8, AND 16 ADJACENT BLOCKS, TO SHOW THE EFFECT OF SIZE OF PLAT ON VARIABILITY.

Four adjacent blocks in a group.	a 14	652	529.75–725.25	37.36	49.08	7.53	443.18	387.25–497	26.76	30.93	6.98
	b 14	681.48	617.75–748.25	30.84	35.75	5.25	465.30	389.50–576	45.62	33.86	11.57
	c 14	713.61	624.50–825	53.14	61.46	8.47	504.64	413.75–587.50	31.84	41.90	8.30
	d 14	676.78	488.25–801.50	70.96	85.80	12.67	441.71	386.75–493.25	26.37	31.49	7.13
Average		680.97	565.06–775.00	48.07	58.02	8.48	463.71	394.31–538.44	32.65	39.34	8.49
Eight adjacent blocks in a group.	a 14	666	636.13–829	24.57	31.57	4.74	454.21	398.62–510.25	27.86	37.97	8.36
	b 14	695	586.50–706.75	55.93	70.30	10.11	473.18	394.12–545	31.55	40.01	8.45
Average		680	611.31–767.87	40.25	50.93	7.42	463.69	396.37–527.62	29.70	38.99	8.40
Sixteen adjacent blocks in a group.	14	680	603.75–797.06	35.43	48.87	7.20	463.71	406.69–509.38	21.67	26.43	5.70

TABLE XV.—*Yield of Turkey wheat grown in 224 block plats (each 5.5 feet square) in 1909 and 1910*—Continued.

SUMMARY BASED ON THE AVERAGE OF BOTH SEASONS, SHOWING THE EFFECT ON COEFFICIENT OF VARIABILITY OF INCREASING THE SIZE OF PLAT AS COMPARED WITH DISTRIBUTING THE SAME AREA BY A SYSTEMATIC METHOD.

Number of blocks combined in each group.	Number of groups averaged.	Coefficient of variability.		
		Plats increased in size, blocks adjacent.	Plats distributed systematically.	Four adjacent blocks combined and combination distributed 4 times=16 blocks.
1	224	13.25	13.25	3.42
4	56	8.48	5.44	
8	28	7.91	3.03	
16	14	6.45	1.80	

SUMMARY BASED ON THE YIELDS OF 1909, ARRANGED TO SHOW THE RELATION BETWEEN SIZE OF PLAT AND AVERAGE DEVIATION.

Shape of plat.	Number of blocks in plat.	Total number of plats.	Average deviation.	Average deviation when plats are made up by systematic method.	
				Every—	Per cent.
			Per cent.		
1	1	224	9.76		
1 by 2	2	112	8.57		
1 by 4	4	56	7.16	56th block	5.05
2 by 2	4	56	7.38		
2 by 4	8	28	6.05	28th block	2.96
1 by 8	8	28	6.08		
2 by 8	16	14	5.30	14th block	1.53
4 by 8	28	8	5.37		
7 by 8	56	4	5.29		

Starting with a coefficient of variability of 13.25 per cent, it is decreased to 8.48 when the block is made 4 times as large, to 7.91 per cent when 8 times as large, and to 6.45 per cent when increased 16 times in size. Table XV gives the result of repeating the same number of plats equal distances apart. Here we see that where the plats are repeated 16 times the average variability for the two years rapidly decreases to 1.8 per cent.

It might appear from a study of the first part of this table that if the size of the plat were constantly increased the variability would be constantly reduced. However, increasing the size of the plat beyond a certain point does not continue to remove the cause of variability, namely, variation in soil. The last part of the table, which contains the data for 1909, is arranged to show the effect of increasing the size of the plat. It indicates a rapid decrease in variability up to plats 16 blocks in size, but no decrease in the next two cases. While acre plats are probably less variable than tenth-acre plats and tenth-acre plats less variable than hundredth-acre plats, yet plats of this size are too variable for direct comparison and they are much too large

for practical plant-breeding work. On the other hand, repeating the plats in a systematic way constantly removes the cause of variation as the number of repetitions increases. It then appears that the most practical method of removing error is to repeat series of small blocks a rather large number of times.

CONSTANCY OF VARIATION ON THE SAME PLATS.

Table XV gives statistical data for 1909 and 1910 on the same blocks arranged in the same way both years. Figure 12 shows the average yield of each section and the average percentage of nitrogen in the two years for sections *a*, *b*, *c*, and *d*. The yield per block varied about the same for the two years, being highest in section *c* in both seasons. The variation in nitrogen was not as regular, section *c* being highest in nitrogen in 1909, while in 1910 there was a small but regular increase in nitrogen from *d* to *a*. The second part of figure 12 shows the coefficient of variability in both yield and percentage of nitrogen when the small blocks are combined in sets of four (Table XV). Section *a* was highest in variability of both yield and nitrogen content in 1909 and low in 1910. Section *b* was low in variation in yield in 1909 and high in 1910. This would indicate that different seasons do not affect equally all parts of the plat, and illustrates the difficulty of "standardizing" plats by the system of sowing all plats to one crop for a season in order to determine relative yield.

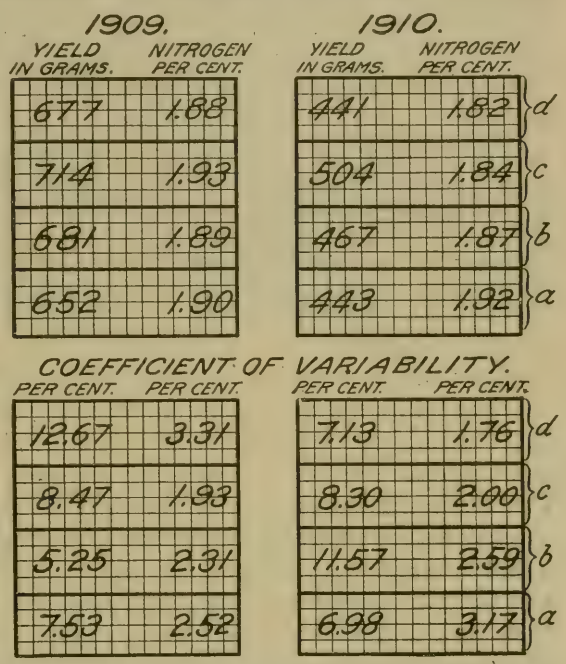

FIG. 12.—Diagrams showing Turkey wheat grown in 224 blocks, combined in four groups (Table XV, *a*, *b*, *c*, *d*) of 56 adjacent blocks to show variations in yield and nitrogen content in 1909 and 1910.

VARIATION IN YIELDS FROM CENTGENER PLATS.

The centgener method consists of planting 100 plants in a centgener, 6 inches apart each way, making blocks 5 feet square. In 1908, 178 centgener blocks were compared for variability with an equal number

of duplicate row plats 16 feet in length. The variability was found to be practically the same. Other data confirm this conclusion, although under unfavorable conditions centgener plats are quite variable, owing to the fact that the individual plants are so far apart that the missing plants are not compensated for by the tillering of neighbors, as is the case where the planting is at the normal rate.

ALTERNATING CHECK ROWS AS A MEANS OF OBTAINING COMPARATIVE YIELDS.

In order to test the value of the method of alternating check rows, the 500 rows before referred to (pp. 36–37) were used as a basis for data. It was assumed that every odd-numbered row would represent a check row, while every even-numbered row would represent a strain being compared with a check row. Thus, row No. 2 would be considered a strain to compare with rows 1 and 3 as checks. It is apparent from data heretofore presented that the error would be too great if only a single row were compared with its adjacent checks. For example, there are numerous cases in the 500-row plats where the even-numbered row would be 20 to 30 per cent higher or lower in yield than the average of the adjacent odd-numbered row plats. Table XVI shows the result of averaging five odd rows and the adjacent five even rows, i. e., rows 1, 3, 5, 7, and 9 are averaged to compare with rows 2, 4, 6, 8, and 10. In the first 10 rows, for example, the five odd rows averaged 235.6 grams per row and the five even rows 226.4 grams per row, or 9.2 grams less than their checks. In the next block the even rows yielded 9 grams more than the checks. Out of the 50 cases here cited the extremes vary from −26.6 to +32.8, with an average deviation of 10.14 grams or 4 per cent. In selective work it is the unusually high variants that are sought after, but with an experimental error greater than the expected variation they would be difficult to locate. Table XVI also shows the result of dividing the 500 rows into blocks of 20 and 40 rows and comparing the yield of odd and even rows in each case. While in most cases the average deviation is small, yet there are a number of quite wide variations. For example, when 50 series of five odd rows are compared with five even rows, 17 series, or about one-third, show a deviation greater than 5 per cent of the mean; when 25 series of 10 odd rows are compared with 10 even rows, 6 series, or about one-fourth, show greater than 5 per cent average deviation; and when 12 series of 20 odd rows are compared with 20 even rows, none show 5 per cent deviation.

EFFECT OF INCREASING LENGTH OF ROW.

To increase the length of the row will decrease the error in about the same way as to increase the size of the block. In the 500-row plats just discussed most of the rows were in series and end to end,

FIG. 1.—HEAD-TO-ROW NURSERY, IN WHICH 25 GRAINS FROM A SINGLE HEAD ARE PLANTED IN A ROW 20 INCHES LONG.

The second year the seed from each 20-inch row is planted in a 16-foot row.

FIG. 2.—ROW-PLAT NURSERY, IN WHICH THE ROWS ARE 16 FEET IN LENGTH WITH A 4-FOOT ALLEY ADJACENT, THUS MAKING THE BEDS 20 FEET IN WIDTH.

These beds are slightly rounded, to give perfect drainage.

FIG. 1.—INCREASE PLATS OF ONE-THIRTIETH ACRE EACH.
Selected strains from the nursery are tested in these plats for 3 years.

FIG. 2.—INCREASE PLATS HARVESTED AND READY TO THRASH.
The plats in this field averaged 60 bushels per acre.

with only a narrow alley a few inches in width between the ends. By adding together the rows end to end, longer rows could be made. (Pl. I.) A total of 84 rows 64 feet in length was made in this manner, and the yields calculated. Table XVI gives the variability in the original 500 rows, each 16 feet long, in comparison with the same rows when combined into lengths of 64 feet. By increasing the length four times the deviation and variability are reduced not quite one-half. The longer rows are also less variable than blocks of five adjacent 16-foot rows, but more variable than five rows distributed in a systematic way throughout the plat.

The best length of row to use must be determined by circumstances. If sufficient uniform land is available and it is more convenient to make long rows, to do so would lessen the number of repetitions of plats necessary to reduce the error within proper limits, but it would always take a larger area to secure the same degree of accuracy with the long rows.

TABLE XVI.— *Yield, in grams, of Turkey wheat grown during the season of 1910 in 500 rows, each 16 feet in length.*

ARRANGED BY ODD AND EVEN ROWS AND AVERAGED IN GROUPS OF TEN.[1]

Rows 1 to 100.			Rows 101 to 200.			Rows 201 to 300.			Rows 301 to 400.			Rows 401 to 500.		
Odd.	Even.	Difference.	Odd.	Even.	Difference.	Odd.	Even.	Difference.	Odd.	Even.	Difference.	Odd.	Even.	Difference.
205	212		246	244		258	253		259	292		278	230	
226	222		235	298		233	241		317	340		278	238	
245	231		230	245		262	219		314	285		277	280	
262	238		248	226		182	220		223	219		307	300	
240	229		266	231		246	239		238	262		283	295	
235.6	226.4	− 9.2	245	248.8	3.8	236.2	234.4	− 1.8	270.2	279.6	9.4	284.6	278.6	− 6
180	183		228	226		224	218		198	223		268	250	
214	255		242	266		222	261		251	287		258	250	
256	220		220	227		256	234		223	204		253	250	
216	234		213	235		229	241		209	223		242	239	
237	256		225	245		292	198		229	194		189	287	
220.6	229.6	9	225.6	239.8	14.2	244.6	230.4	−14.2	222	226.2	4.2	242	255.2	13.2
214	231		271	212		235	229		216	216		284	276	
235	208		235	238		235	271		222	204		200	217	
284	316		247	227		235	212		245	236		316	285	
275	240		247	255		221	242		231	194		194	243	
272	228		267	296		273	269		200	218		363	343	
256	244.6	−11.4	253.4	245.6	− 7.8	239.8	244.6	4.8	222.8	213.6	− 9.2	271.4	272.8	1.4
272	239		269	259		219	255		228	200		248	294	
275	215		250	289		270	280		227	228		380	338	
224	237		278	246		275	191		218	208		326	287	
220	240		222	256		282	249		242	257		265	315	
182	263		308	276		268	237		221	230		314	290	
234.6	238.8	4.2	265.4	265.2	− .2	262.8	242.4	−20.4	227.2	224.6	− 2.6	306.6	304.8	− 1.8
156	252		297	280		213	246		215	252		328	273	
227	263		230	310		255	269		269	210		324	315	
254	224		323	263		235	242		171	228		300	279	
226	188		317	261		247	268		230	207		252	249	
246	255		305	268		303	242		222	200		331	273	
221.8	236.4	14.6	294.4	276.4	−18	250.6	253.4	2.8	221.4	219.4	− 2	307	277.8	−29.2

[1] Average difference in yield between odd and even rows, grams, 10.4; per cent, 4.

TABLE XVI.—*Yield, in grams, of Turkey wheat grown during the season of 1910 in 500 rows, each 16 feet in length*—Continued.

ARRANGED BY ODD AND EVEN ROWS AND AVERAGED IN GROUPS OF TEN—Continued.

Rows 1 to 100.			Rows 101 to 200.			Rows 201 to 300.			Rows 301 to 400.			Rows 401 to 500.		
Odd.	Even.	Difference.	Odd.	Even.	Difference.	Odd.	Even.	Difference.	Odd.	Even.	Difference.	Odd.	Even.	Difference.
227	247		275	249		257	225		282	246		224	303	
230	285		241	269		190	204		269	240		349	320	
263	281		285	245		227	250		250	230		272	283	
255	255		249	222		222	174		233	268		291	331	
280	280		246	223		208	216		213	200		208	271	
251	269.6	18.6	259.2	241.6	−17.6	220.8	213.8	− 7	249.4	236.8	−12.6	268.8	301.6	32.8
275	237		232	228		229	187		200	207		269	293	
264	277		200	228		200	215		219	233		293	327	
268	227		282	242		238	238		225	207		257	263	
204	218		227	239		242	202		205	230		254	244	
237	202		246	222		190	245		243	216		250	311	
249.6	232.2	−17.4	237.4	231.8	− 5.6	223.8	217.4	− 6.4	218.4	218.6	.2	264.6	287.6	23
235	229		266	287		218	212		250	208		286	243	
204	210		351	312		212	184		276	254		297	403	
257	312		265	300		234	267		235	245		316	285	
294	295		322	313		211	213		243	255		297	239	
313	315		293	285		232	284		257	281		211	247	
260.6	272.2	11.6	299.4	299.4	0	221.4	232	10.6	252.2	248.6	− 3.6	281.4	283.4	.2
233	265		248	273		230	219		298	316		208	219	
276	214		233	243		236	228		261	208		255	255	
327	300		280	261		290	314		225	248		243	289	
312	316		259	263		208	195		233	226		247	275	
370	290		248	272		225	219		205	214		249	266	
303.6	277	−26.6	253.6	262.4	8.8	237.8	235	− 2.8	244.4	242.4	− 2	240.4	260.8	20.4
271	236		241	250		232	211		250	230		217	215	
251	246		266	254		185	257		254	211		235	285	
269	251		310	263		242	242		205	269		252	235	
217	242		245	245		279	270		237	216		222	289	
298	308		275	269		265	270		242	192		271	288	
261.2	256.6	− 4.6	267.4	256.2	−11.2	240.6	250	9.4	237.6	223.6	−14	239.4	262.4	23

SUMMARY OF ODD AND EVEN ROWS ARRANGED IN BLOCKS OF 20 AND 40 ROWS TO SHOW DEVIATION.

The 10 odd and 10 even rows from each adjacent 20 grouped together.						The 20 odd and 20 even rows from each adjacent 40 grouped together.		
Odd.	Even.	Difference.	Odd.	Even.	Difference.	Odd.	Even.	Difference.
228.1	228.0	− 0.1	222.6	224.7	+ 2.1	236.7	234.8	− 1.9
245.3	241.7	− 3.6	239.2	242.5	+ 3.3	245.7	252.6	+ 6.9
236.4	253.0	+16.6	246.1	252.9	+ 6.8	258.8	255.5	− 3.3
255.1	252.2	− 2.9	225.0	219.1	− 5.9	268.1	257.2	−10.9
282.4	266.8	−15.6	235.4	228.1	− 7.3	264.4	263.9	− .5
235.3	244.3	+ 9.0	235.3	233.6	− 1.7	245.8	237.9	− 7.9
259.4	255.4	− 4.0	241.0	233.0	− 8.0	229.1	229.1	0
276.8	259.0	−17.8	263.3	266.9	+ 3.6	242.6	247.7	+ 5.1
268.4	268.6	+ .2	271.0	288.8	+17.8	230.2	223.6	− 6.6
260.5	259.3	− 1.2	287.9	289.7	+ 1.8	238.1	233.3	− 4.8
240.4	232.4	− 8.0	273.0	285.5	+12.5	267.1	277.8	+10.7
251.3	243.5	− 7.8	239.9	261.6	+21.7	280.4	287.6	+ 7.2
235.7	233.6	− 2.1						
			Average difference.		7.256	Average difference.		5.483

SUMMARY SHOWING RESULT OF COMBINING 16-FOOT ROWS IN VARIOUS WAYS.

Classification.	Extreme variation.	Standard deviation.	Coefficient of variability.	Classification.	Extreme variation.	Standard deviation.	Coefficient of variability.
			Per cent.				*Per cent.*
500 single rows 16 feet long	156–403	35.85	14.33	5 adjacent rows 16 feet long	212–317	26.11	10.38
84 rows 64 feet long (4 times length of above)	196–284	21.43	8.8	5 rows 16 feet long distributed (every 100 rows)	227–278	14.44	5.77

Table XVII shows a comparative summary, based on the data herein reviewed, from which it appears that to repeat the 5.5-foot square blocks, in series, will reduce the error at the greatest rate, while to repeat the 16-foot rows will give the next most rapid reduction. However, the method of alternating 5 odd rows with 5 even rows gave about as good results as to repeat 10 rows, and the system of alternate planting with check rows would sometimes be desirable.

TABLE XVII.—*Summary showing coefficients of variability under various systems of arranging block plats and row plats.*

Kind of plats and arrangement.	Number of plats combined.					Remarks.
	1	5	10	15	20	
Blocks 5.5 feet square (Table XV):						
Adjacent	13	8	7	6.4	.....	Variation will not continue to decrease.
Repeated	13	5	2.5	1.8	.....	Variation decreases to infinity.
Rows 16 feet long (Table XVI):						
Adjacent	14	11	7	5	3.5	Variation does not continue to decrease.
Repeated	14	5	4	3.2	3.7	Variation decreases to infinity.
Alternated	14	.....	4	3.6	3	Do.

To correct by check plats is sometimes uncertain, as pointed out hereafter, and therefore the advantage seems to be with the method of systematic repetition of rows or blocks. The repetition of the square blocks 10 times gave a higher degree of accuracy than repeating rows even 15 and 20 times, and it seems probable that further experimenting is likely to show the block system to be the most accurate for close comparisons. It also does away with the competition which no doubt takes place between adjacent rows, and also makes note taking easier by giving a mass effect, such as is secured under field conditions. To increase the size of plat will also reduce error, as shown by Table XV, and on the basis of these data a plat, about three times the size of the 5.5-foot blocks reported on, is being tested. This block is 4.2 by 16 feet in size, and indications are that with this block the variation will be reduced about one-half, as compared with the 5.5-foot block.

INFLUENCE OF RATE OF PLANTING ON YIELD.

For several years in planting our row plats care was taken to plant the same number of seeds in each row. In case of wheat, 400 kernels usually were planted to the 16-foot row, which was equivalent to the normal rate of seeding, or 5 pecks per acre. However, in 1908 and 1909 counts of the number of plants harvested were made of many rows at harvest time. In the row plats of wheat where the rate of seeding was about normal it was found that only about 60 to 80 plants

were harvested to every 100 kernels planted. A variation of 20 per cent in stand was not apparent to the observer because all plats would appear to have an equally good stand at harvest time. This loss of plants was due to many causes, such as winterkilling, insects, and accidents, but chief among the causes appeared to be the normal competition of plants. For example, certain plants were weak or were slow in starting spring growth; the stronger plants would quickly outdistance them, causing at least a certain percentage of the weaker plants to perish as a result of competition. It seemed doubtful, however, whether this difference in plants harvested had a marked effect on yield. For example, here and at many experiment stations tests have been made with sowing wheat at various rates, from 4 pecks to 10 pecks per acre. The difference in yield is never large. Doubling the amount of seed sown, from 4 to 8 pecks per acre, does not double the yield, and in many cases does not affect it at all. This is due to the tillering power of the plant, which is able in this way to compensate for the difference in number of plants.

To make a test of the rate of planting under row-plat conditions, a series of plats was planted with Red Rustproof oats in the spring of 1910. Each row plat was 16 feet in length. There were 5 plats in the series, planted at the rate of 400, 500, 600, 700, and 800 grains per plat. The series was repeated 20 times, making 100 rows in all. The results are shown in Table XVIII.

TABLE XVIII.—*Results of rate-of-seeding test on 100 16-foot rows of Red Rustproof oats.*

Statement of averages.	Number of grains sown per row.				
	400	500	600	700	800
Number of plats averaged	20	20	20	19	20
Average yield per row.....grams..	197	213	215	215	234

The normal rate of seeding would have been about 600 grains per row. It appears from the data that a slight variation in rate of planting, as 25 or 50 grains more or less than normal, would not affect the results.

To further test the effect of rate of seeding, a series of 60 blocks was laid out, each block being 5 drill rows wide and 16 feet in length. As the drill rows were 10 inches apart, this made the plats each 4.2 by 16 feet. The blocks were planted with a small drill devised for the purpose. Five rates of seeding were used, namely, 42.6, 49.1, 55.9, 65.4, and 73.3 grams per block. The series was repeated 12 times, giving 12 blocks of each rate for averaging. The results are shown in Table XIX.

TABLE XIX.—*Results of rate-of-seeding test on 60 block plats of Kherson oats.*

Statement of averages.	Weight of seed sown (grams).				
	42.6	49.1	55.9	65.4	73.3
Number of blocks averaged	12	12	12	12	12
Average yield per block.....grams..	1,069	1,101	1,151	1,149	1,156

The normal rate of seeding would be about 60 grams per block, and it is apparent from the data that a variation of 10 or even 20 per cent above or below normal in the weight of seed used would not have a marked effect on the yield.

In view of the data just presented, it would seem not to be necessary to actually count the number of seeds to be planted in each small plat, providing some other quicker means can be found of obtaining approximate accuracy. If the seed is first carefully fanned, scoured, and screened to one size, equal volumes will usually not vary more than a small percentage in number of kernels. Also equal weights will have approximately the same number of kernels, provided the seed has first been carefully prepared by fanning and screening to a uniform size.

EFFECT OF COMPETITION BETWEEN ADJACENT ROWS.

In 1908 it was observed that a certain strain of early wheat in a series of row plats made a very poor appearance at harvest time, while the same strain planted in centgeners made a much better comparative showing. Apparently the larger and faster growing strains on each side, the rows being only 8 inches apart, exercised some competitive effect. This effect of competition has been noted for two years since. Also in certain variety tests of oats, grown in row plats 10 inches apart, the same effect was noted. Exact data can not be given on this point, as the results from the series of plats planted in 1909 and in 1910 for this purpose were seriously impaired by unfavorable conditions; but Table XVIII, giving results from adjacent row plats sown at different rates, shows that the 800-seed rate made a marked increase over the 700-seed rate, while in a similar series of blocks (Table XIX), sown at the same rate, this marked increase was not noted. Since the 800-seed row was always adjacent to the 400-seed row, it may have had some advantage on this account. Danger from this source can probably be avoided if care is taken to plant only similar varieties in adjacent rows. Where the block plat is used this source of error is eliminated.

VARIATION IN PURE STRAINS AND RELATION OF DATA IN CENTGENER NURSERY AND IN FIELD PLATS

ISOLATION OF PURE STRAINS.

In 1902, Dr. T. L. Lyon, now of Cornell University, planted 800 heads of Turkey winter wheat in a centgener nursery, arranging to keep a record of the progeny of each head. The heads were numbered from 1 to 800 and these original numbers are still retained as family numbers. The original plan was to select for increased nitrogen content and yield, discarding those families which did not show high averages in both these respects, and to practice continuous selection of individual plants from among those families that were promising. A considerable number of the families were discarded each year, until at the end of harvest in 1906 only 47 of the original 800 were retained for further work. At this time the writer took up the work and the practice of continuous selection was discontinued as it began to be apparent that the isolation of pure strains was a more promising way of obtaining results. The 47 pure strains were put in field plats to test for yield. Complete records, however, can be given on only 24 pure strains, as all but 26 were dropped in 1908 for lack of space, and the nursery data are incomplete on 2 strains out of the 26. These strains are shown in field plats in Plate II. Table XX gives the average results for four years, both in the centgener nursery and in the field plats. By "centgener" is meant the method of planting 100 seeds from a single plant in a square plat, the plants 6 inches apart each way.

TABLE XX.—*Relations of certain characters of 24 strains of Turkey wheat grown in nursery and in field and tested during 4-year periods.*

RANKED IN GROUPS OF FIVE IN ORDER OF YIELD IN THE FIELD.

Family No. (The numbers in italic indicate the five highest yielders.)	Data from centgener nursery (average for four years, 1906–1909).							Data from field plats (average for four years, 1907–1910).[1]		
	Nitrogen content.	Yield per—		Average weight of kernels, 1903–1906.	Strength of straw.	Fruiting period.	Number of centgeners averaged.	Nitrogen content.	Yield.	Number of plats averaged.
		Plant.	Centgener, 1906–1908.							
	P. ct.	*Grams.*	*Gms.*	*Grams.*	*P. ct.*	*Days.*		*P. ct.*	*Bush.*	
48	2.66	13.38	764	0.02192	80	36	22	2.60	40.75	9
287	2.52	12.38	704	.01864	81	35	23	2.49	40.59	12
42	2.68	11.58	622	.02105	63	35	23	2.48	39.90	5
312	2.61	12.27	646	.02344	68	36	31	2.55	39.21	9
425	2.70	9.83	612	.01824	67	35	35	2.56	39.18	8
Total or average	2.63	11.89	670	.02058	72	35	134	2.54	39.93	43
556	2.72	12.36	593	.02267	55	36	38	2.54	38.86	5
225	2.53	11.12	623	.01984	65	35	29	2.55	38.78	10
215	2.63	11.14	605	.02064	70	34	48	2.54	38.64	8
47	2.60	12.26	664	.02013	63	36	123	2.51	38.50	39
3	2.70	11.01	620	.02168	63	34	18	2.53	38.48	23
Total or average	2.64	11.58	621	.02099	63	35	256	2.53	38.65	85

[1] Averages of check plats: Nitrogen content, 2.61 per cent; yield, 35.18 bushels.

TABLE XX.—*Relations of certain characters of 24 strains of Turkey wheat grown in nursery and in field and tested during 4-year periods*—Continued.

RANKED IN GROUPS OF FIVE IN ORDER OF YIELD IN THE FIELD—Continued.

Family No. (The numbers in italic indicate the five highest yielders.)	Data from centgener nursery (average for four years, 1906–1909).							Data from field plats (average for four years, 1907–1910).		
	Nitrogen content.	Yield per—		Average weight of kernels, 1903–1906.	Strength of straw.	Fruiting period.	Number of centgeners averaged.	Nitrogen content.	Yield.	Number of plats averaged.
		Plant.	Centgener, 1906–1908.							
	P. ct.	*Grams.*	*Gms.*	*Grams.*	*P. ct.*	*Days.*		*P. ct.*	*Bush.*	
391	2.70	10.93	510	.02185	64	34	28	2.51	37.96	5
221	2.63	12.46	647	.02295	64	34	59	2.59	36.57	12
313	2.50	11.95	597	.02118	68	36	114	2.53	36.27	5
377	2.81	11.05	563	.02016	60	34	20	2.70	36.13	5
206	2.59	11.08	558	.01889	65	34	26	2.58	36.12	5
Total or average	2.65	11.49	575	.02111	64	34	247	2.58	36.61	32
314	2.68	9.70	560	.02020	66	34	52	2.63	35.22	8
168	2.63	10.70	512	.02247	63	34	23	2.60	34.84	8
526	2.76	10.03	614	.02029	66	34	18	2.73	34.20	5
379	2.84	10.79	620	.02057	62	24	20	2.71	33.56	5
216	2.52	12.11	594	.02108	66	35	43	2.48	33.46	8
Total or average	2.69	10.67	580	.02089	65	34	156	2.63	34.26	34
209	2.49	11.38	570	.01915	82	34	37	2.45	32.93	8
37	2.87	11.27	526	.02270	54	34	48	2.75	32.58	5
2	2.56	9.86	548	.02180	58	36	33	2.55	31.88	8
328	2.62	11.89	508	.02522	62	33	30	2.73	28.88	5
Total or average	2.63	11.10	538	.02228	64	34	148	2.62	31.56	26

SUMMARY OF RESULTS, ARRANGED IN GROUPS OF FIVE STRAINS AND RANKED IN VARIOUS WAYS.

CENTGENER TESTS.										
In order of nitrogen content:										
37, 379, 377, 526, 556	2.80	11.10	583	0.02128	59	34	144	2.69	35.07	25
425, 391, 3, 314, *42*	2.69	10.61	585	.02060	65	34	156	2.54	38.15	49
48, 221, 168, 215, 328	2.63	11.91	607	.02224	68	34	182	2.61	35.94	42
312, 47, 206, 2, 225	2.58	11.32	608	.02082	64	35	242	2.55	36.90	71
287, 216, 313, 209	2.51	11.95	616	.02001	74	35	217	2.49	35.81	33
In order of strength of straw:										
209, *287*, *48*, 215, *312*	2.58	12.11	658	.02076	76	35	161	2.53	38.42	46
313, *425*, 314, 526, 216	2.63	10.72	595	.02020	67	35	262	2.59	35.67	34
206, 225, 391, 221, 3	2.63	11.32	592	.02104	64	34	160	2.55	37.58	55
42, 168, 47, 379, 328	2.67	11.44	585	.02189	63	34	219	2.61	35.14	62
377, 2, 556, 37	2.74	11.13	558	.02183	57	35	139	2.63	34.86	23
In order of yield per plant:										
48, 221, *287*, 556, *312*	2.63	12.57	671	.02192	70	35	173	2.55	39.20	47
47, 216, 313, 328, *42*	2.58	11.96	597	.02173	64	35	333	2.55	35.40	62
209, 37, 215, 225, 206	2.62	11.20	576	.02024	67	34	188	2.57	35.81	36
377, 526, 3, 391, 379	2.76	10.76	585	.02091	63	34	104	2.64	36.07	43
168, 2, *425*, 314	2.64	10.02	558	.02068	63	35	143	2.58	35.28	32
In order of yield per centgener:										
48, *287*, 47, 221, *312*	2.60	12.55	685	.02041	71	35	258	2.55	39.12	81
225, *42*, 3, 379, 526	2.70	10.91	620	.02068	64	34	108	2.60	36.98	48
425, 215, 313, 216, 556	2.61	11.48	600	.02076	65	35	278	2.53	37.28	34
209, 377, 314, 206, 2	2.63	10.61	560	.02040	66	34	168	2.58	34.46	34
37, 168, 391, 328	2.70	11.20	514	.02306	61	34	129	2.65	33.56	23
FIELD-PLAT TESTS.										
In order of nitrogen content:										
37, 526, 328, 379, 377	2.78	11.01	566	.02179	61	34	136	2.72	33.07	25
314, *48*, 168, 221, 206	2.64	11.46	608	.02129	68	34	182	2.60	36.70	42
425, 2, 225, *312*, 556	2.62	11.09	604	.02120	63	36	166	2.55	37.58	40
215, 3, 313, 391, 47	2.63	11.46	604	.02120	66	35	331	2.52	37.97	80
287, *42*, 216, 209	2.55	11.86	622	.01998	73	35	126	2.47	36.72	33
In order of yield per acre:										
48, *287*, *42*, *312*, *425*	2.63	11.89	670	.02058	72	35	134	2.54	39.93	43
556, 225, 215, 47, 3	2.64	11.58	621	.02099	63	35	256	2.53	38.65	85
391, 221, 313, 377, 206	2.65	11.49	575	.02111	64	34	247	2.58	36.61	32
314, 168, 526, 379, 216	2.69	10.67	580	.02089	65	34	156	2.63	34.26	34
209, 37, 2, 328	2.63	11.10	538	.02228	64	34	148	2.62	31.56	26

To sum up, the 24 pure strains have varied in the centgeners from 2.49 to 2.87 in per cent of nitrogen, from 54 to 82 per cent in strength of straw, from 9.70 to 13.38 grams in yield per plant, and from 508 to 764 grams in yield per centgener. They also have shown a variation

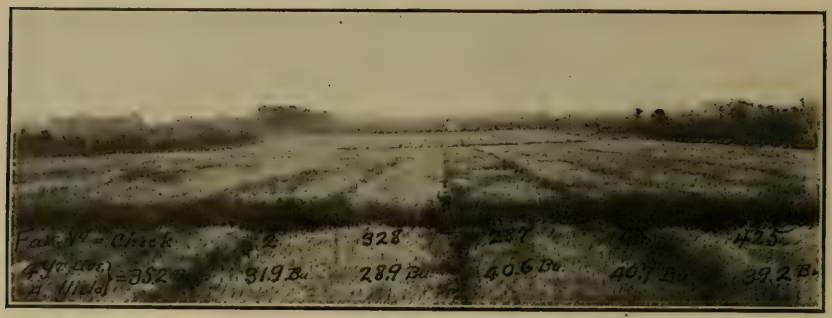

FIG. 13.—Field plats of pure strains and check plats of original seed of Turkey wheat, 1910. The upper numerals are family numbers; the lower, 4-year average yields. Two of the poorest yielders out of 26 strains came adjacent to two of the best. The difference in yield would not have been suspected from the appearance of the plats.

FIG. 14.—Wheat nursery plats, showing variations in winterkilling. Pure strains were alternated with the original Turkey wheat from which the strains were isolated. The original was mostly winterkilled while many of the select strains withstood the winter well.

in average weight of kernel ranging from 0.01824 to 0.02522 gram. In the field plats the percentage of nitrogen varied from 2.45 to 2.75 and the yield per acre from 28.8 to 40.7 bushels—a difference of about 12

bushels. Some of these plats and the check plats noted below are shown in figure 13. It is interesting to note that the check plats of original unselected Turkey winter wheat averaged 35.18 bushels per acre, or about halfway between the highest and lowest pure strains. More strains surpass the check in yield than fall below it, but this is probably because a large percentage of the poor-yielding strains were discarded after the first field test in 1907. It appears that neither the original selection of the 800 heads, nor the discarding of centgeners in the nursery, nor the continuous selection of high-yielding plants within the centgeners had any effect on eliminating the poor yielders. There was a marked difference in the appearance of the pure strains, some

FIG. 15.—Field plats, showing variations in winterkilling between two pure strains of Turkey wheat. Strain No. 377 is shown at the right and No. 102 at the left; No. 377 withstood the winter almost perfectly.

having short grains and others long grains. They also varied in color, lodging, and general appearance in the field, both in fall growth and spring growth. Figures 14, 15, 16, and 17 illustrate these variations better than they can be described.

Table XX also shows the data from Table XV grouped in series of 5, and arranged in various ways to illustrate relationships. The principal considerations in this work were the improvement of wheat in nitrogen and yield. Records were kept of many characters of the plant in the nursery, but evidence points to six that are of interest, namely, (1) nitrogen content, (2) yield per plant, (3) yield per centgener, (4) weight of kernel, (5) strength of straw, and (6) length of fruiting period.

PERCENTAGE OF NITROGEN.

The percentage of nitrogen is in inverse ratio to strength of straw and length of fruiting period, but has no direct relation to other characters. It is transmitted in the field plats as indicated in the summary of Table XX. A striking example of this conclusion is seen in a comparison of families Nos. 209 and 37, Table XX. These families represent the two extremes in percentage of nitrogen and strength of straw, with an inverse relation, but are nearly the same in all other characters.

From 1903 to 1906, records were kept of individual plants selected from the nursery. When these plants were classified according to

FIG. 16.—Increase rows of Turkey wheat, showing variations in the time of heading in different strains, each from a single plant. Four rows of each strain are grown.

percentage of nitrogen or size of kernel, regardless of the family from which they came, there was a marked inverse relation, the percentage of nitrogen increasing as the size of kernel decreased. It seems probable, however, that the individual plants having small kernels may have suffered some degree of arrested development, since this relation disappears when the pure strains are so classified. Percentage of nitrogen and yield per acre in field plats vary inversely.

STRENGTH OF STRAW.

Strength of straw varies inversely with percentage of nitrogen and directly with yield per acre and yield per centgener.

FIG. 1.—TYPE OF ROAD GRADER OR DRAG USED IN GRADING A NURSERY INTO BEDS 20 FEET WIDE TO AFFORD UNIFORM DRAINAGE.

FIG. 2.—GRAINS OF TURKEY WHEAT, SHOWING VARIATION IN APPEARANCE.

Nos. 51 and 60 are typical kernels from two pure strains and represent the shortest and longest kerneled types out of 80 strains. No. 76 is a hard, vitreous kernel, somewhat approaching the durum wheat in type. No. 75 is a soft wheat. The plants of this strain are typical Turkey in appearance but the grain is larger and almost white. Notwithstanding the white color, this strain was the highest in nitrogen content of 80 strains in 1910.

FIG. 1.—REPRESENTATIVE KERNELS FROM 4 STRAINS OF TURKEY WHEAT, SELECTED TO SHOW VARIATION IN APPEARANCE.

No. 48 is a large plump-kerneled strain, while No. 287 has a rather small kernel. No. 328 has a large dark-colored kernel, while No. 313 has a decided yellow color and is long and pointed.

FIG. 2.—REPRESENTATIVE KERNELS FROM 4 STRAINS OF TURKEY WHEAT, SELECTED FROM A SERIES OF 80 STRAINS TO SHOW VARIATION IN QUALITY.

On the basis of a perfect wheat, grading 100, these strains grade as follows: No. 77 grades 50, No. 51 grades 70, No. 27 grades 80, and No. 42 grades 95.

YIELD PER PLANT.

The yield per plant shows some correlation to yield per acre and yield per centgener, but this correlation is not high, as it is only in the first class that the correlation is marked. One of the best-yielding strains (No. 425) had a small plant yield in the nursery.

YIELD PER CENTGENER.

The yield per centgener shows a high correlation with yield per acre and strength of straw, but not a close relation to other characters.

SIZE OF KERNEL.

The size of kernel (Pl. III, fig. 2) appears to have no fixed relationships; as a character of a pure strain it seems to be independent of other characters. An example of this is shown in Table XX. Families

FIG. 17.—Field plats of Turkey wheat, showing variations in stiffness of straw in two strains. Each strain originated from a single plant.

Nos. 287 (Pl. IV, fig. 1) and 425 have small kernels, but they are among the best in yield, while No. 328 (Pl. IV, fig. 1) is poorest in yield, but has the largest kernel. Nos. 48 and 287 are the best yielders out of the 26 strains (Table XX), averaging 40.7 and 40.6 bushels per acre, respectively, in a four-year test. No. 48 has a large, plump kernel, while No. 287 has a rather small kernel. No. 328 has averaged 28.9 bushels under the same conditions, yet this strain has a large, dark-colored kernel. Our records do not seem to show a relation between the appearance of the berry and the yield. No. 313 has averaged 36.3 bushels per acre, but the kernel has a decided yellow color, and is long and pointed in shape, approaching a rye grain in type.

QUALITY OF KERNEL.

As already noted, there does not seem to be a definite relation between the appearance of the berry and the yield of the strains.

Plate IV, figure 2, illustrates four strains of Turkey wheat selected from a series of eight strains to show variation in quality. On the basis of a perfect wheat grading 100 these strains grade as follows: No. 77 grades 50, No. 51 grades 70, No. 27 grades 80, and No. 42 grades 95. These grades indicate the variation in quality found in pure strains and show the great possibility of improving quality (fig. 18).

To sum up, high yield in the field is associated with high yield per centgener and strong straw, has a slight relation to size of plant, no relation to size of berry, and varies inversely with percentage of

FIG. 18.—Cereal laboratory, showing the method of taking notes on quality. Comparisons of 80 strains of Turkey wheat are being made. There were 10 plats of each strain, making 800 in all, but the 10 samples of each strain are arranged together. Notes are taken on each sample separately, then an average is made of the results. To facilitate note taking, a set of "standard samples" representing different qualities is kept in long, 2-ounce vials. A set of these vials is plunged into the sample, and by comparison very accurate data are obtained.

nitrogen. A high or a low nitrogen content as indicated in the nursery gives correlated results in the field. High nitrogen content is antagonistic to high yield. However, an occasional strain, such as No. 48, combines a fair percentage of nitrogen with high yield.

SUPERIORITY OF STRAIN.

From the point of view of yield per acre there would seem to be little choice among the five best strains (Table XX), but in some ways No. 48 is outstanding in desirable qualities. With a high yield

per acre, it still is above the average in nitrogen content, has a strong straw and a large berry of good appearance. It is also very winter resistant, as was shown in the severe winter of 1909–10, when it came through with much less winterkilling than standard varieties, such as Big Frame and ordinary Turkey wheat.

COMPARISON OF ROWS, CENTGENERS, BLOCKS, AND FIELD PLATS.

In 1909–10 the 26 strains of Turkey wheat were sown in field plats and duplicated in rows, centgeners, and blocks, but this portion of the nursery was winterkilled. However, very good results were obtained with 11 varieties of oats sown in the spring of 1910 in all four ways. The field plats were one-fifteenth of an acre in size and

FIG. 19.—Block nursery, showing blocks 4.2 by 16 feet in size. The beds are slightly elevated, as in the row nursery.

were repeated three times. Each variety was repeated 10 times in centgeners, rows, and blocks. The centgeners were each 5 feet square and contained 100 plants 6 inches apart each way. The rows were 12 feet in length and the grain sown in them at the rate of 10 pecks per acre, the usual rate of seeding in this region. The blocks were each 4.2 by 16 feet, or 5 drill rows wide (fig. 19), and sown at the usual rate of seeding. The results summarized in Table XXI show a high degree of correlation between the yield of the field plats and the rows and blocks, but practically no correlation in the case of centgeners. Except for the Lincoln oat, which yielded exceptionally high in the nursery, the correlation in the rows and blocks would be very high.

TABLE XXI.—*Yields of grain from 11 varieties of oats grown in field plats, centgeners, rows, and blocks.*

[The field plats were repeated 3 times, the others 10 times.]

Variety.	Average yield of thrashed grain.			
	Field plats, per acre.	Centgeners.	Rows.	Blocks.
	Bushels.	*Grams.*	*Grams.*	*Grams.*
Burt	60.7	729.2	238.2	1,196.8
Texas Red	60.6	622.9	206.9	1,047.2
Average	60.65	676.05	222.55	1,122.0
Swedish Select (01)	55.8	584.3	213.5	865.8
University No. 6	55.3	572.8	178.0	867.1
No. 855	55.2	473.7	167.0	809.8
Average	54.77	543.6	186.16	847.56
American Banner	51.9	550.9	170.4	800.8
Lincoln	51.8	654.4	207.3	1,071.5
No. 1174	51.0	601.3	184.2	842.5
Average	51.56	602.2	187.3	904.93
Average without the Lincoln oat		576.1	177.3	821.6
Swedish Select (09)	50.3	560.4	170.8	791.1
No. 611	49.8	581.1	174.3	760.4
No. 70	49.3	470.3	159.6	776.7
Average	49.83	537.26	168.23	776.26

It is possible that the lack of correlation with the centgeners in the last three groups is due to the fact that the lower yielding ones were rather late, coarse-strawed, and rank-growing strains. Under the thin planting of the centgeners every plant had opportunity to develop to full size, which probably gave a slight advantage to the later and coarser types, which was not apparent under the usual rate of seeding. Table XX, giving results for 24 strains of Turkey wheat, shows a perfect correlation between yield of centgener and field plats, wherein the wheat strains were all similar, there being no great difference in time of maturity or habit of growth. This suggests that when similar strains are being compared data on the average yield of centgeners would be reliable, but that in the case of dissimilar varieties, especially of large ones and small ones, the results would not be comparable with those obtained under field conditions.

COST OF PLANTING AND HARVESTING CENTGENERS, ROWS, AND BLOCKS.

When a large number of strains is being tested in rows or blocks and the series is repeated ten to twenty times, the question of time and relative cost becomes one of importance. Rapidity of planting and harvesting is probably the matter of first consideration, as it is desirable to have these operations performed in the shortest possible time in order to secure comparable conditions.

Table XXII is a summary showing the relative number of plats of each kind that can be planted in a day by one gang of men, based on our experience. All preliminary work, such as preparing the land, sorting and labeling the seed, preparing stakes, etc., is done beforehand. However, there is usually time for preliminary work, so that

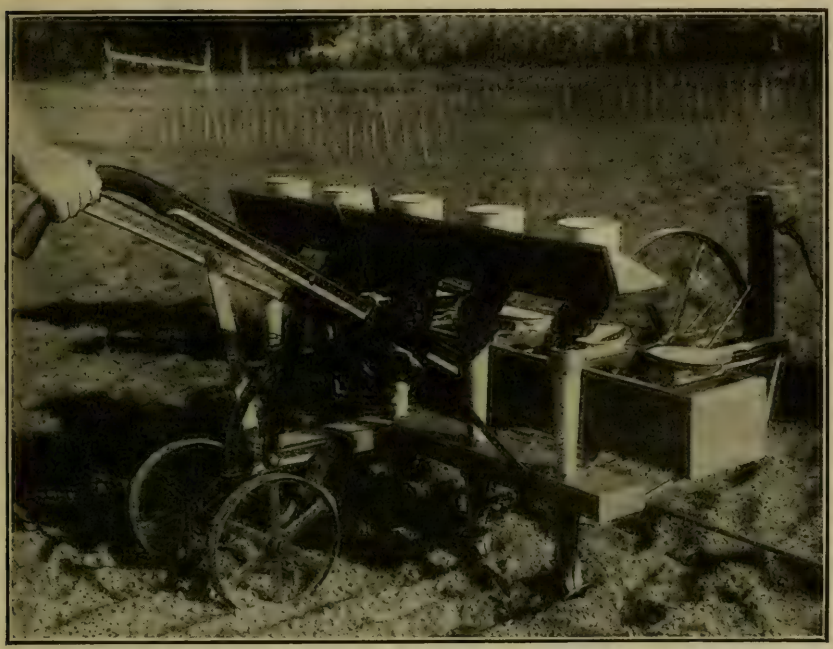

FIG. 20.—Five-row nursery drill used for planting row plats and block plats. Four or five men with this drill will easily plant 500 row plats in a day, where not more than 100 row plats could be planted by hand. The work of the drill is also more uniform and satisfactory than planting by hand.

the method of planting that permits the greatest rapidity has some advantage. The planting is done with a nursery drill (fig. 20), the harvesting with hand sickles (fig. 21), and the thrashing with a small power machine.

TABLE XXII.—*Comparative number of plats of different types that can be planted or harvested in 10 hours.*

Kind of plat.	Men in gang.	Number of plats covered in 10 hours.		
		Planted.	Harvested.	Thrashed, weighed, etc.
Centgener, using centgener planter	5	100	250	500
16-foot row plat, row made with hoe or spade and planted by hand	5	100	500	750
16-foot row plat, planted with nursery row drill	5	500	500	750
Block 4.2 by 16 feet, planted with nursery row drill	5	150	200	250

USE OF CHECK PLATS.

In nursery work where plats are repeated 10 or more times the checks will not be needed as a means of correcting error. Their principal use here is to determine the degree of experimental error. For example, in 1910 we had in one series 80 strains of Turkey wheat. The series was repeated 10 times, making 800 rows in all, but every fifth row was a check, making 200 check rows. To determine the experimental error, the 200 check plats are grouped in sets of 10, taking 1 plat from each series, the same as in grouping the strains. This method gives 20 sets of 10 checks each, and the range of experimental error to be allowed for is at once apparent.

FIG. 21.—Row plats at harvest time. Each plat is harvested with a hand sickle and the stake tied into the bundle. The bundles from the row plats that are to be kept pure for seed should be covered with cheese cloth or paper bags.

Another important use of checks is as a standard by which to judge progress, and this judgment can be formed very well if the original stock from which selections were made is used for checks.

Figure 22 illustrates the method of selection when the experimental error is determined by the use of checks. Let the figure illustrate an ideal case where any number of strains are being compared for yield, the yield varying from 200 to 320 pounds. Let line *eh* represent this variation. A series of check plats shows a variation ranging from 240 to 280, represented by line *cj*. The mean yield of the checks is

260, with an extreme error of 20 above or below the mean. The limits of error for the line *ch* are shown by the lines *dg* and *fi*. To be sure that a certain strain was better than the check plats its yield must fall outside the line *cl* or be better than 280. In the same way two strains can not be compared without making an allowance of 40. For example, 320 is not surely better than 280, since they both might equal 300, but we are sure 320 is better than anything less than 280. If the extreme variation of checks should equal the variation in strains or varieties, then selection would not be possible. On the other hand, if the error in checks is zero, direct comparison between strains could be made, and small differences would be significant. This illustration emphasizes the importance of knowing the probable experimental error and having it well within the limits of expected variation if results are to be secured by selection.

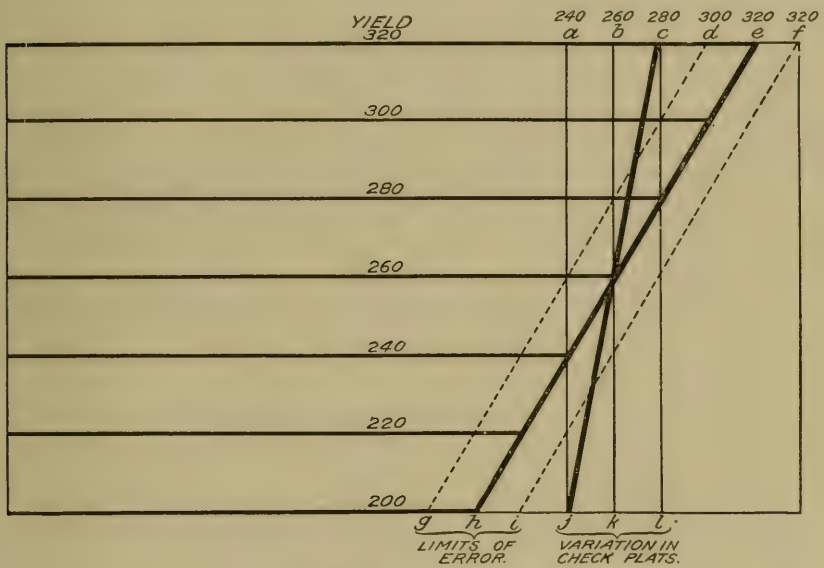

FIG. 22.—Diagram showing the method of selection for yield when the experimental error is known.

ERROR IN CHECK PLATS.

By reference to Table XVI it is seen that where odd and even numbered (alternate) row plats are checked against each other there is a certain experimental error. If this error should be large, it would be unsafe to correct by the checks. For example, if the yield of a certain check variety equals 100, but in series A its yield, due to error, should be 105, and in series B only 95, a correction of yield by these checks would introduce an error of 10 per cent. It might happen that the strain used for checks would be the most variable strain

in use in some particular season, though reliable at other times. For this reason care should be taken to ascertain the experimental error in checks before using them for correction, else a greater error may be introduced by their use than by discarding them.

OTHER PRECAUTIONS AGAINST ERROR.

ACCIDENTAL INJURY TO PLATS.

A problem which always confronts the experimenter at harvest time is what to do with plats injured from some cause, such as the damage of burrowing animals, being partly washed out by floods, etc. Where a plat is obviously injured it should be discarded. To allow for accidents we have adopted the plan of planting one or two extra series to be discarded or used, as is needful, at harvest time. In this way plats accidentally injured may be discarded without disturbing the regular number in the series.

UNEQUAL DRAINAGE.

Unequal effects of winter injury are partly due to unequal distribution of moisture in the soil. Wherever there is a depression run-off water may collect and increase the soil moisture. In some cases, as in a very dry spring, these slight depressions may have an advantage, while at other times these low places suffer from winterkilling. Perfect drainage is very important and can be easily secured by laying off the nursery in slightly elevated beds about 20 feet in width. This bedding can be quickly accomplished by the use of a road grader or road drag (Pl. III, fig.1).

SUMMARY.

(1) When 14-foot or 16-foot row plats are used as checks or sown in duplicate, great variation is found in yield, owing to natural unequal effects of the environment. When the row plats are repeated only five or six times, the extreme error will still be large, owing to the chance combination of high or low variants.

(2) Systematic repetition constantly reduces error as the number of repetitions increases, but with 16-foot row plats 10 to 20 repetitions must be made, depending on the degree of accuracy desired.

(3) It is probable that the greater the number of strains to be compared the more repetitions will be necessary, because of the greater area they will cover.

(4) Small blocks, 5.5 feet square, give results similar to those of the row plats, except that the reduction of experimental error is somewhat greater as a result of repetition. Blocks repeated 8 to 10 times give results apparently about as accurate as rows repeated 15 to 20 times.

(5) To increase the size of the block, up to a certain limit, rapidly decreases variability; but error can not be indefinitely decreased by continuing to increase the size of the plat, as it can be by repetition.

(6) Variability is not constant from year to year on the same plats.

(7) To alternate with check rows gives a high degree of accuracy, with a few extreme variations, when as high as 10 or more checks are used. The total number of plats required for the same degree of accuracy, however, is greater by this method than by systematic repetition.

(8) To increase the length of the row 4 times decreases deviation about one-half.

(9) By increasing the length of the row or the size of the block, the number of repetitions necessary is decreased, but the total area required to secure the same accuracy is increased. An excellent size, where land is plenty, would be 2 to 4 rods in length for rows, and 5 by 16 feet in area for blocks.

(10) The rate of planting, within certain wide limits, has little influence on yield.

(11) There is some competition between adjacent rows, especially when varieties very different in habit of growth are planted side by side. The use of blocks does away with this source of error.

(12) Pure strains differ in a very marked way in most important characters. High yield in the field is associated with high yield in the nursery plats, and strong straw has a slight relation to size of plant, no relation to size of berry, and varies inversely with the percentage of nitrogen.

(13) Block plats and row plats at the usual rates of seeding will probably correlate more closely with results in field plats than in plats where the plants are spaced, as in centgeners.

(14) Where error is corrected by the system of repetition of plats, check plats should be used for the purpose of determining the experimental error. When the variation in checks equals the variation in strains, no possible selection can be made.

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